AMERICAN METER PRACTICE

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PREFACE

THE subject of metering the output of central stations has been to me one of the most interesting of the many problems arising in the development of the supply of current for various commercial needs. There are many minor details omitted in the work, which would doubtless prove of interest to the practical worker in meters, but, however poorly set forth, the effort is made to outline the underlying principles of operation and practice and leave the minor details to be worked out to suit local conditions.

In describing only a few meters my object is to select one each of well known and representative types and not to weary the reader by reciting the same characteristics held by a number of meters of the same type.

Any intention of slighting in any way many excellent meters, herein mentioned but not described, is entirely foreign to the purpose of this work. The meters selected have each some distinguishing feature which makes them representative of as many respective classes.

To the consumer of power who is not a technical man, Chapter XIII, on How to Read Meters, will probably be of most interest since it will enable him to figure out and check up his meter bills. This knowledge should bring about the very friendliest relations between the supplier and consumer of electricity.

LYMAN C. REED.

CONTENTS

AMERICAN METER PRACTICE.

CHAPTER I.

Measurement of Power in Direct Current Circuits.

Electrical measurements in the laboratory have been carried on for many years with great accuracy. The conditions are carefully studied when a determination of some quantity is sought, and the errors which effect the accuracy of the measurement eliminated. The study of the phenomena of electricity is rightly called an exact science, but the perfecting of an accurate commercial meter has been a slow and tedious process. At first the principles of correct design were not embodied in the meters put on the market, and no matter how perfect they were made mechanically a correct registration of the power consumed could not be obtained. But, as a rule, the mechanical features were more defective than the theoretical ones, and the combination of these defective elements has given the meter of commerce an unenviable reputation.

Such great inventors as Edison, Thomson, Shallenberger and Duncan have spent much time in trying to get together various elements in suitable combination to meet the requirements and accurately measure the current or the power in the many various applications and uses to which electricity is put. Edison gave us the chemical ampere hour meter, which has done yeoman service in the

metering of direct currents; and Thomson gave us his recording wattmeter, which has gradually been developed into an excellent meter, and which can be used for both direct and alternating current. Shallenberger and Duncan produced at first ampere hour meters for alternating current, but in later years wattmeters, also, for alternating current. There is a large number of other meters, but these four are the pioneers in the meter field. In each meter different principles are involved, which meet more or less successfully the requisite of a good commercial meter. Heat and cold, moisture, dust, insects and vibration are some of the physical obstacles to be met and overcome by the successful meter; and short circuits, overloads, light loads and no loads are some of the electrical conditions under which it must operate. The wearing qualities of all of the elements of the meter must be taken into consideration. As in the one-horse chaise, each part of the meter should be as strong as any other part. The ability to withstand the test of time; the property of being the same meter at the end of one year's use, is the real test of the value of an instrument. The problem, then, becomes one of combining certain elements in such relation to each other as to form a perfect measuring device, and the maintaining of this same relation in the face of the various conditions which are partially enumerated above. However clearly these principles were recognized twenty years ago, the state of the art was such that only very imperfect devices were produced as meters.

It has been only within the last few years that commercial meters have been brought to a reasonable state of efficiency. The vast interests involved have quickened the managements of central stations to the importance of having better meters and meter service, and the field of in-

vention is so attractive along these lines that we see each year a gradual improvement in the design and performance of the meters placed on the market.

The measurement of any form of transmitted energy is always attended by a diminution of the energy transmitted equal to the amount consumed in the measuring device.

Hence all instruments that measure transmitted energy are shunt instruments, the power shunted or diverted from the transmission being usually a very small fraction of the total power. We may class all such devices as shunt dynamometers to distinguish them from absorption dynamometers, which usually translate the energy to be measured into heat or mechanical work and destroy its original properties.

The measurement of electrical energy which is transmitted is accomplished by means of shunt dynamometers. Its translation into useful commercial forms is accomplished by absorption dynamometers of various classes, such as motors and incandescent lamps.

For the sake of analysis the flow of electrical energy is usually considered by treating its two components, quantity and intensity, as individual entities, and instruments are constructed which will measure each separately as well as the product of the two.

In commercial circuits the voltage or intensity usually remains constant, in which case a measurement of the power flowing in a circuit may be obtained by the recording of the variable quantity of current in amperes and multiplying by the known voltage. If the amperes remain constant, and the voltage vary, a record can be obtained of the power flowing by recording the variable voltage and multiplying by the known amperes of the circuit. If both

the voltage and the amperage of the circuit be variable their product gives the power flowing, which, for convenience, is usually indicated by one instrument called a wattmeter.

In the first class of instruments, the ammeter class, the loss in energy due to the insertion of the instrument in the circuit is directly proportional to the current flowing.

The voltmeter, if on a constant potential circuit, has a constant energy consumption The wattmeter has a constant energy consumption in its potential circuit plus a variable energy loss in the series circuit proportional to the current flowing.

From the foregoing the deduction follows that on constant potential circuits of known intensity the measurement of the energy passing is the most economically carried out by an ammeter, on circuits of constant and known amperage with variable voltage by a voltmeter, and where both current and voltage are variable by a wattmeter.

These general statements hold true for the measurement of the power in a direct current circuit, or a non-inductive alternating circuit, but must be modified for inductive alternating circuits containing reactance and capacity, the effects of which will be brought out in Chapter II.

It is assumed that the reader is familiar with the well-known forms of indicating ammeters, voltmeters and wattmeters on the market, the descriptions of which are, therefore, omitted.

Many of these instruments record the passing power of a circuit with extreme accuracy, but being simply indicators of the instantaneous values of the power they do not give a summation of this power during the elapsed time.*

*See Flather's Dynamometers and Measurement of Power.

In order that an instrument may bring in the element of time in the measurement of power, it must constantly move some object, for one unit of energy passing, through unit distance in unit time; and this movement must be permanently recorded by means of a dial train, or some similar summation device. Then, when n units of energy are passing, the recording object will be moved through n units of distance in unit of time. The application of this principle to commercial recording meters has resulted in

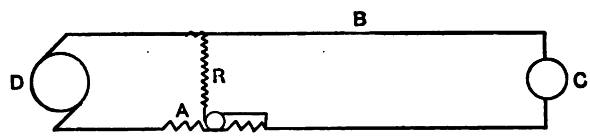


FIG. 1.

a great number of types, the most prominent of which are described in succeeding chapters.

The various classes of electrical energy to be measured commercially resolve themselves into:

Direct current as distributed by two or three-wire systems.

Alternating current, single and polyphase systems.

Direct current distributed by means of a five-wire system is also used to some extent, but, as the principles involved in its measurement are identical with those of the two and three-wire systems, the five-wire system will not be considered separately.

Two-wire direct current systems are usually confined to 500 volt, and arc circuits. The three-wire system is the well known Edison system, the local distribution of which may be either two or three-wire.

The amperes flowing in the simple two-wire circuit with load at C, Fig. 1, are the same in every part of the circuit.

An ammeter placed at A reads the same as if placed at B, but the energy in the circuit varies as the distance from D, becoming less as C is approached, and is directly proportional in a circuit of uniform resistance to the distance from D. Hence the mean power in the circuit would be found at some point between D and C.

It is customary in an ordinary two-wire service to meter the energy passing at A, and, if the fall of potential, or loss of energy, between A and C be small, the error is not great, the allowable loss usually not exceeding two per cent., hence one per cent. less energy than that recorded at A would represent the mean energy passing in the given circuit.

As the meter in commercial practice is placed at the entrance of the service into a building, the consumer usually pays for about one per cent. more energy than he actually receives at his translating devices.

Should the meter be a recording ammeter, one leg of the circuit only passes through the instrument; if a wattmeter be used the other leg of the circuit must be brought into the meter to enable the potential coils of the instrument to be energized.

In a recording wattmeter, the product of the magnetization set up by the series and shunt field coils must exert a resultant torque on some movable member of the meter which will cause it to move in a manner to record n units of energy in n units of time.

The movable members of a recording instrument have, unfortunately, an appreciable amount of friction which introduces an inertia factor operating as a counter torque to the product of the energy torque by a function of time. This friction of the moving parts is small, and, at full load of the meter, the ratio between the counter torque, due to friction,

and the energy torque is negligible. As the load decreases, the ratio between the counter frictional torque and the energy torque approaches unity; in other words, there is a certain point in every recording instrument where the energy torque and frictional torque are equal. When this point is reached the instrument remains at rest.

The counter frictional torque varies in different instruments of the same and different makes from a fraction of one per cent. to three or four per cent. of full load energy torque, the large losses often being due to causes arising in service.

For this reason, it is customary in commercial recording instruments to compensate for this friction by introducing

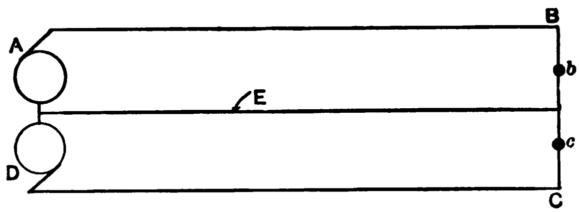


FIG. 2.

an additional torque which is a definite fraction of full load value, and which compensates through all ranges of load for the initial friction of the meter.

Theoretically this is a very pretty way of accomplishing the result, but exactions of service introduce frictions which this compensation does not entirely eliminate.

The power passing in a three-wire circuit is usually measured by metering the two outside legs, although equally good results can be obtained by metering one outside leg and the neutral conductor.

In the three-wire circuit, Fig. 2, let *A*, *B*, *D*, *C* be the

outside legs, E the neutral conductor, and b and c translating devices.

When the currents in A B and D C are equal no current flows in E; when they are unequal E carries the difference positive or negative. The energy flowing on each side of the system can be measured by two two-wire meters, or one three-wire meter. In either case, the series coils carry the varying amperes of each side of the system, while the shunt field coils are energized proportionately to the voltage of the system.

If two two-wire meters be used, the same connections are made as in a two-wire system. If a three-wire meter be used, the two series fields are superposed to form a resultant field proportional to the current flowing in both sides of the system. The torque due to this resultant field and the field set up by the potential circuit operates the meter in such a manner as to record the total energy passing in the three-wire circuit.

A form of meter which is not manufactured commercially, so far as the author is aware, can be constructed to measure the total energy flowing in a three-wire circuit by placing one series coil of an ordinary three-wire meter in one outside leg of the circuit and a coil of half the number of turns in series with the neutral. The power registered is multiplied by two.

To illustrate, suppose A B, Fig 2, to carry 50 amperes, positive, and D C 25 amperes, negative, then the neutral wire, E, carries 25 amperes, negative. As the neutral field coil has half the number of turns, the sum of the magnetizations of the series fields is equal in effect to a positive current of 37.5 amperes. Twice this amount is 75 amperes, or the same as the series fields of the ordinary three-wire meter would carry in the example given.

The I^2R losses in the fields of a meter at full load reach an appreciable amount, but at light loads are not of much consequence, hence, in the form of meter just given, on a properly balanced three-wire service the I^2R losses would be halved as the neutral would carry no current. On unbalanced loads the loss in this form of meter would be reduced by some quantity varying between the limits of $\frac{1}{2}$ and $-\frac{1}{4}$, so that an average saving in I^2R losses in the field coils for any meter would be $12\frac{1}{2}$ per cent. In reality this would be much larger, as any serious unbalancing would scarcely take place except at light loads, when the I^2R losses are negligible.

The shunt field coil, where a single meter is employed, can be fed from across the outside or between the neutral and one outside. In either arrangement, unless the voltage be equal on both sides of the system, an error is introduced into the record proportional to the difference of voltage existing. To obtain a true record, if the voltage be unequal, it is necessary to employ two two-wire meters or a three-wire meter having two armatures fed respectively from each side of the system.

The latter arrangement amounts to the combining of two meters under one cover, resulting in a clumsy and expensive device. In commercial practice the voltage on one side of a three-wire distributing system is usually maintained about equal to that on the other; the errors resulting from inequalities of the sides supposedly balance, so that it is the usual practice to meter with a three-wire meter with the shunt field coils fed between the two outsides or between one outside and neutral.

In meters of the class described, the torque urging the rotary part at any given moment is proportional to the energy of the current at that moment, while, to record

correctly, the speed must be proportional to the energy, and, consequently, to the torque. This result is secured by providing a breaking device in which the resistance offered to rotation is proportional to the speed.

This brake may be of various constructions, but the usual form is that of a conducting non-magnetic metallic disk revolving between the poles of a permanent magnet. The eddy currents generated in the disk, by their reaction on the permanent magnetic field, exert a resistance to movement which varies in amount proportionately to the speed of the torque exerted by the moving member to which the disk is fixed. Hence, the power necessary to generate the eddy currents becomes proportional to the torque exerted on the moving member or the watts passing in the circuit. Other forms of brakes are employed, such as fans and liquid brakes, but they have given place in the latest types of meters to the now universal magnetic brake.

CHAPTER II.

Measurement of Power in Alternating Current Circuits.

In passing to the measurement of alternating currents, simple two and three-wire non-inductive single-phase circuits will be first considered.

The power flowing in a non-inductive two-wire circuit is at any instant the product of the instantaneous values of the current and voltage. To get the mean power the in-

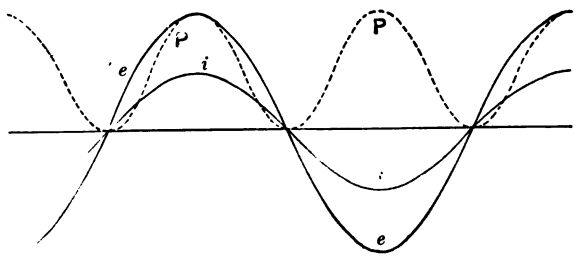


FIG. 3.

stantaneous values must be integrated through a complete cycle. Graphically we may represent such a power as in Fig. 3, wherein e represents the sine wave of varying voltage values for a single period and i the varying ampere values for the same period in phase with the voltage. The curve p then represents the varying power values, and is obtained by multiplying the corresponding ordinates of the voltage and current curves.

The product of the mean effective volts and amperes gives the mean effective watts passing in the circuit or the mean value of the power curve p, hence, for all non-inductive circuits, $Pe = \frac{e\,i}{2}$ true watts.

If the current flowing in curve i be passed through a coil of wire and another coil be energized by a current proportional to and varying with the voltage curve e, the two coils, if so placed, will form a resultant magnetization for any instant of time proportional to the product of the instantaneous values of e and i or the watts passing in the circuit.

If a movable member or armature be provided, of such character that it is moved by the operation of this resultant magnetization in such manner that its speed is proportional to the watts passing in the circuit, a record of the power passing is obtained. In recording the flow of alternating current energy this principle has been used in the development of two classes of meters, which for convenience are styled inductive and non-inductive.

A non-inductive meter can be used for either direct or alternating current. A familiar type is the Thomson recording wattmeter. In this type of meter the field coils are in series with the current flowing, the shunt field coils are energized proportionately to the voltage of the circuit, and the torque exerted on the armature is for any instant proportional to the product of the instantaneous values of the current and E. M. F., hence the mean torque is proportional to the product of effective volts by effective amperes, or the true watts passing in the circuit.

The method of connecting this meter is the same as on direct current circuits, and, in fact, is interchangeable without recalibration, the error being for practical purpose inappreciable.

The induction meter is either a "current" meter or wattmeter, and operates by means of a "shifting" field acting on a closed secondary armature, the eddy currents induced in the armature reacting on the shifting or rotating field in such manner as to produce a torque proportional to the energy or current passing, according to whether it is a "current" or wattmeter.

A well-known type of current meter is the Shallenberger in which the series current passes through a primary coil set at an angle with a closed secondary within it, the plane of the two magnetizations being at a like angle and differing in phase. Mounted in inductive relation is a thin disk armature in which eddy currents are generated by the shifting or rotating field. The reaction of these resultant fields tends to revolve the armature, the torque being proportional to the square of the current.

A fan brake, whose retarding effect increases as the square of the speed, is attached to the spindle on which the armature is carried, and enables the meter to record the current flowing.

In the wattmeter, of which there are many types, the series and shunt field coils are wound in inductive relation to a movable closed secondary or armature in which eddy currents are induced proportional to the magnetizations set up in the series and shunt field coils. The shunt field coils are displaced in phase from the series coils by having a reactance placed in series with them, the magnetizations thus creating a shifting or rotating resultant field.

The field set up by the induced eddy currents in the revolving secondary lags behind the resultant field set up by the series and shunt field coils, creating a torque on the secondary which is proportional to the square of the energy flowing. The providing of a brake, whose retarding

force varies as the square of the speed, enables the energy passing to be obtained from the speed of the revolving spindle to which the armature is attached. There are many variations and different arrangements of the foregoing general principles.

The power passing in an inductive single-phase circuit may be graphically illustrated by Fig. 4, wherein the current lags behind the voltage by 60°.

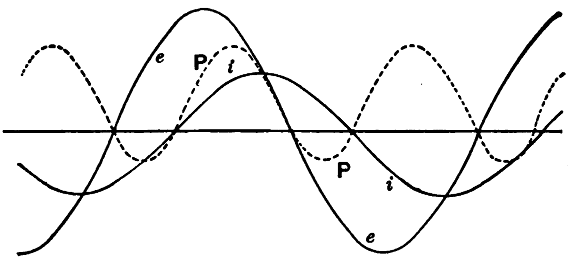


FIG. 4.

The resultant power curve p represents the watts passing in the circuit, and is written $Pe = \frac{e\,i}{2} \cos. \vartheta$ angle of lag.

The power passing in an alternating circuit at any instant is equal to the product of the *instantaneous* values of the current and voltage, etc. (see *American Electrician*, March, 1902), and acts as a generator for a portion of each period, the useful power being the difference between positive and negative values of the curve p.

The resultant torque, therefore, exerted on the coils of a meter in circuit with an inductive load is not proportional to the product of the virtual volts and virtual amperes as measured by an indicating instrument, but to this product multiplied by the power factor of the circuit; the power factor is the ratio between the true and apparent watts.

In the metering of three-wire single-phase systems, inductive or non-inductive, the same general principles outlined in the foregoing hold true.

Multiphase systems are a combination of single-phase systems differing in phase from each other, and are used in distributions for light and power owing to the ease with which motors can be operated thereon.

The systems in general use are the quarter-phase and three-phase, the former composed of two single-phase circuits differing by 90° and distributed by either four or three-wires, the latter of three single-phase circuits differing by 120° and distributed by either four or three-wires.

The quarter-phase system, employing four wires for its distribution, is metered exactly as two separate single-phase circuits would be, the total power in the two-phases being the sum of the energy components of each phase. When the two phases are balanced, that is, have the same amount of energy passing in each phase, it is only necessary to meter one phase and multiply the result by two to get the total amount of energy passing. When the phases are unbalanced, that is, have different loads on each phase, two meters are necessary, one in each phase, to register the energy passing.

In the commercial distribution of this system it is the usual practice to take a lighting circuit into a customer's premises from one phase only and a power circuit from both phases. The motor furnishes a balanced load and needs only one meter and the lights one meter. In this way, by loading up the phases equally, the number of meters needed for metering the lights can be kept down to one meter per customer.

When three wires are used in the distribution of two-phase currents, one wire acts as a common return for the

other two, and the instantaneous value of the current on the common return at any instant is the algebraic sum of the instantaneous values of the currents of each phase.

The virtual resultant value would be the hypothenuse of a right triangle which would represent the current in phase and value. The resultant voltage is found in the same way, hence the virtual watts would be the product of the resultant current by the resultant voltage for a non-inductive circuit.

As an example, suppose we have a two-phase system carrying 10 amperes in each phase at a voltage of 100 v.,

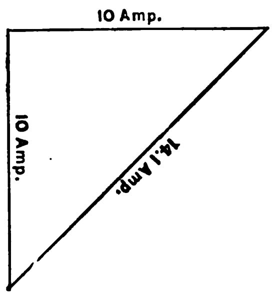


FIG. 5.

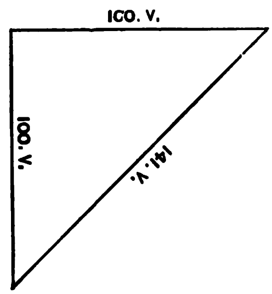


FIG. 6.

the triangle of the current values, Fig. 5, would give a resultant amperage of 14.14, the triangle of the voltage values, Fig. 6, gives a resultant voltage of 141.4 volts. The total watts passing in the circuit is the product of these two resultants, or a watt value of 2,000 watts.

Calculating the watts separately for each phase we have

10 amp., x 100 v. = 1000 watts (1)
10 amp., x 100 v. = 1000 " (2)

2000 watts

which is the same as the above.

The resultant voltage and resultant amperes being the same in phase when the load is balanced, a meter, Fig. 7, with its series field coils placed in the common return and

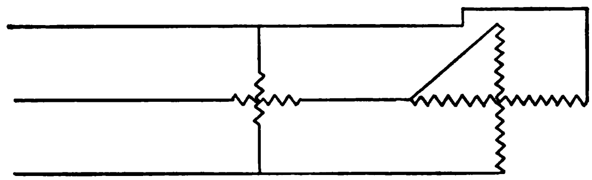


FIG. 7.

its shunt field coils energized by the resultant voltage of the system, would give the true power passing in the circuit.

When the load is unbalanced the resultant ampere value leads or lags behind the resultant voltage of the system and may be displaced in phase either way by 45° on non-inductive load. The true power in the circuit is then obtained by multiplying by the cosine of angle of lag or lead.

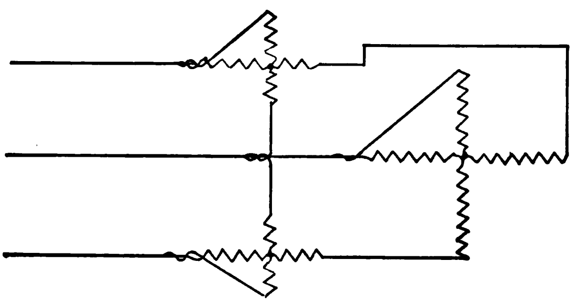


FIG. 8.

As a wattmeter records the product of the instantaneous values and not the maximum values of current and voltage, the record is a true one of the energy passing in the circuit.

This connection, Fig. 7, will not record the true power passing on an unbalanced inductive circuit, as an angle of lag or lead of 45° could give a wattless register, allowing 70 per cent. of the energy passing to remain unrecorded. On balanced circuits, however, feeding induction motors, this connection readily takes the place of the two meters shown in Fig. 8, where the series field coils are connected in the outside legs of the circuit and the potential circuit fed between the given leg in the meter and the common return.

When the induction type of meter is used, the potential circuit is so connected as to differ in phase from the

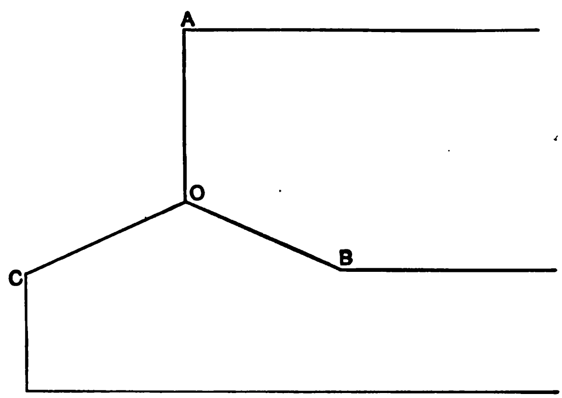


FIG. 9.

series field circuit by 90°, hence in Fig. 8 the potential circuit for each meter would be fed from the given leg in the meter to the other outside. This is the connection most commonly used in metering two-phase circuits. The elements of two meters are often combined under one cover to act on a common armature. The elements are connected in the same manner as though they were separate meters, and need not be further elaborated.

Three-phase circuits are connected in "star" or "delta" grouping; the former sometimes uses four wires in the distribution while the latter is always distributed by means of three wires.

In Fig. 9, the "star" grouping with common centre at *o* is shown, the voltage of the three legs being represented in intensity and phase by the lines *a*, *b*, *c*. The resultant voltage of such a system for any instant of time may be found graphically by producing the single-leg of opposite

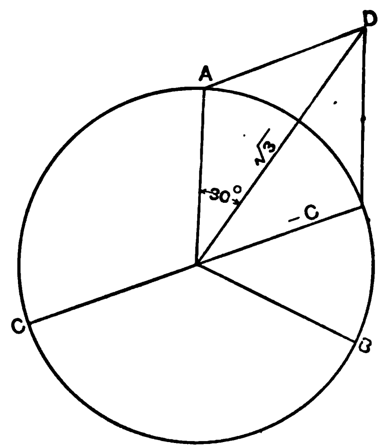


FIG. 10.

sign to the other two backwards, and finding the resultant by the parallelogram of forces. The diagonal will represent in sign and phase the resultant of the voltage on the three legs.

In Fig. 10 the resultant is $\sqrt{3}$ times the voltage of one phase and leading it by 30°. If one phase be selected as the leading one, the resultant voltage will be found to be always leading it by 30°. In the same Fig. 10 in a balanced circuit the current will have a resultant coinciding with

the voltage resultant, and the product of the two resultants will, for non-inductive load, represent the true power passing.

The algebraic sum of the resultants of the voltage taken consecutively between the three legs of a system will equal for any instant the resultant positive or negative value of the voltage at that instant. Likewise, the resultant of the current flowing for any instant is the algebraic sum of the three resultant currents of the system found in like manner. Therefore, the current passing over any two legs of a three-wire three-phase circuit is the algebraic sum of the three resultant currents of the system, hence the power passing in the circuit is the product of the resultant current and voltage. The algebraic product of two minus quantities is always a plus quantity, hence the power passing is always positive in character on non-inductive circuits. On inductive circuits, where the current leads or lags behind the voltage, a minus quantity of current flows for a portion of each period.

Some simple rules deduced from the above may be of service in readily computing the energy passing in polyphase systems.

In "star" or "Y" connected systems, or any system employing a common neutral, the resultant voltage is equal to the effective voltage $\times \sqrt{m}$, m being the number of phases. The resultant amperes flowing in any system is the average of the sum $\times \sqrt{m}$. The energy passing is, therefore, the common resultant voltage $\times$ common resultant amperage $\times$ cos. φ or lag angle. Suppose, for example, the amperes in the different legs of a three-phase unbalanced system are 10, 20 and 30 respectively, and the effective volts of the circuit, taken with regard to a common neutral point or conductor, 100 volts. The average value

of the amperes is 20, and the resultant is $20 \times \sqrt{3} = 34.6$ amperes. The resultant voltage is $100 \times \sqrt{3} = 173$ volts. The cosine of angle of lag φ is taken as .5, corresponding to an angle of 60°.

The energy passing in such a circuit is 34.6 amperes $\times$ 173 volts $\times$ .5 = 3000 watts. The same result is obtained by taking each leg separately, multiplying amperes $\times$ effective volts $\times$ cosine φ = 60 amperes $\times$ 100 V. .5 $\times$ 3000 watts.

The common neutral point or conductor is not always available, hence the advantage of the first method where in practice the resultant voltage is the voltage between any two lines.

Where the current lag angles in the different branches of the circuit are of different values the resultant amperes can be plotted graphically, or the energy of each leg computed by multiplying the apparent watts found by the power factor, and adding the amounts thus obtained to get the total energy of the circuit.

When the neutral point of a star connected system is extended to the distribution, the system becomes three independent circuits with a common neutral, the algebraic sum of the currents on the neutral for any instant being zero.

The energy in a three-phase circuit may be measured by one, two or three meters, or their equivalent, of inductive or non-inductive type.

The non-inductive type of meter has maximum torque when the shunt field coils and series field coils are in phase. Therefore, as the lag angle increases the torque diminishes, until at quarter-phase the torque is zero. Hence, it is impossible in meters of this character to combine series fields of different phases to act in conjunction

with shunt field coils in phase with only one of them to measure the energy passing. The case where only one meter is used to measure unbalanced polyphase energy factors is confined to meters of the inductive type where one or more measuring elements are combined to give a resultant measuring value to a common movable armature.

In Fig. 11, let *A B C* represent a three-phase relation feeding circuit having a balanced load, the series coils of a meter *D* are then placed in either one of the three legs and the shunt field coil fed by the virtual voltage of the system

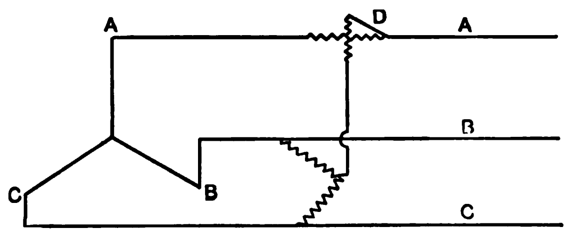


FIG. 11.

obtained from a star connected set of resistances having a common neutral point. This connection applies to either star or mesh groupings. The register of the meter is multiplied by three to obtain the total power flowing in the circuit. That is, the power passing in each leg of the circuit is

$$Pe=\frac{3E\ I}{\sqrt{3}}=\sqrt{3}\ E\ I.$$

In this instance Fig. 11 represents the connection for a non-inductive type of meter. If an inductive meter be used the series and shunt field coils must be displaced 90° in phase, and the meter fed as shown in Fig. 12, wherein the potential circuit is fed between *C B* whose resultant voltage lags 90° behind current in *A*.

One meter is sufficiently accurate for balanced three-phase loads, but, when the load becomes unbalanced, two legs of the circuit must be metered.

If non-inductive meters be employed we connect them as shown in Fig. 13, where the current in A lags on non-

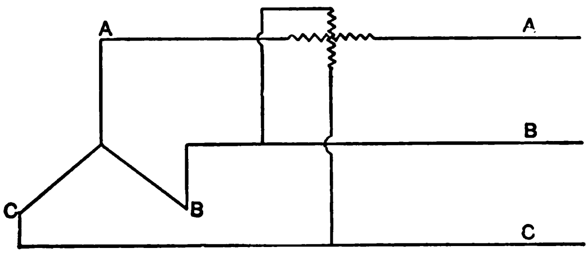


FIG. 12.

inductive load 30° behind the voltage in shunt coil d; likewise, current in b lags 30° behind the voltage in e. The sum of the two registers of the meter is equal to the resultant voltage of the system by the resultant amperes. If the current be inductive, the current in a lags cos. $(\varphi + 30°)$

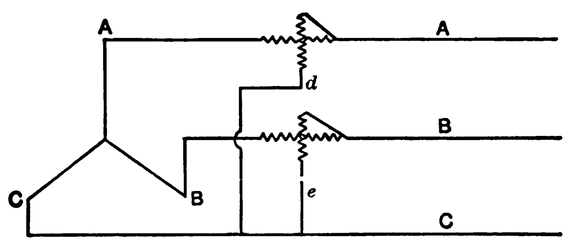


FIG. 13.

behind the voltage; likewise, current in b lags cos. $(\varphi - 30°)$ behind the voltage in e. In other words, the true watts equal the resultant current $\times$ resultant voltage $\times$ cos. φ. The power passing is equal to the algebraic sum of the two

registers. It is easily seen that when $\varphi = 60°$, the expression cos. $(\varphi + 30)$ is equal to cosine $90°$, which gives a wattless register. Under such conditions one meter registers the total current. If the lag angle be greater than $60°$ one meter runs backward.

Instead of the two meters just shown in Fig. 13, one inductive meter may be used which, in general, consists of two elements combined under one cover, in short, two single-phase meters so arranged with regard to a common armature that the power passing is recorded on a single

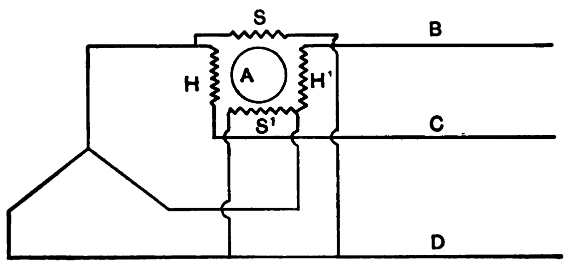


FIG. 14.

dial train. There are many types of this meter, but in principle they bear sufficient resemblance to the one shown diagrammatically in Fig. 14 for it to represent them.

A is a closed secondary or armature in inductive relation to the series and shunt field coils *H*, *H'*, *S*, *S'*, being displaced in phase by $90°$. The maximum torque is therefore exerted when the phase displacement is $90°$, and diminishes as the angle decreases, becoming zero when the two circuits are in phase. This is the condition of the circuit having a lag of $90°$ or wattless current.

This action is just the opposite of the action in the non-inductive meter, where the torque diminishes as the series and shunt field coils become displaced in phase. The

torque of both meters varies, however, with the cosine law, but in opposite directions. Mesh connected systems are metered in the same manner; in fact, the three-wire two-phase Y and mesh connections three-phase are all metered alike.

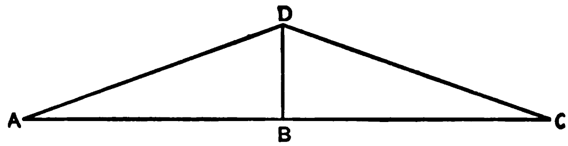


FIG. 15.

The metering of such systems as the monocyclic is worked out along the same general lines, but presents some peculiarities which are interesting.

In the monocyclic system a regular single-phase circuit is used in conjunction with a third wire called the teaser, which differs from the single-phase circuit by 90° in phase.

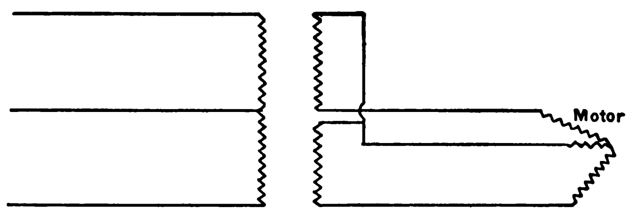


FIG. 16.

In the generator, one end of the teaser coil is tapped on to the middle of the single-phase coil, and the other end leads to a collecting ring. The relation of the E.M.F. in the resulting three-wire circuit may be illustrated diagrammatically in Fig. 15, wherein *A C* is voltage of single-phase, *B* its middle joint, *D B* teaser winding, *A D* and *D C* the resultant E.M.F. between the two wires and the teaser.

Such a system is adapted to the distribution of light and power, the lights being connected to the single-phase in the usual way, and the motors as illustrated in Fig. 16.

As indicated, the primaries of the two transformers are placed in series with the teaser connected to the point of joining. The secondaries are cross connected, forming a resultant lop-sided three-phase relation which is used to operate a three-phase motor in the same manner that a regular three-phase system would do.

Another way of connecting up two transformers to accomplish the same results is illustrated in Fig. 17, wherein a small transformer is shown connected between the teaser

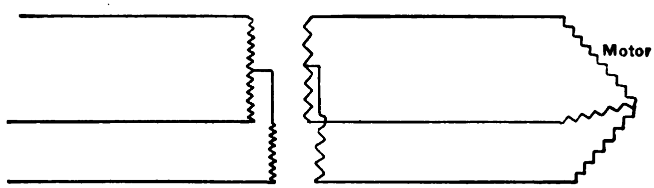


FIG. 17.

and the middle point of the large transformer, the relation of the current in the secondaries then being the same as in the generator.

To meter the power passing in the connection Fig. 16, we proceed exactly as in unbalanced three-phase systems, or two-phase systems employing a common return. Hence, with non-inductive meters we place one in each outside leg and feed the potential circuit between the given leg and common return.

With inductive meters the regular polyphase meter used for three and two-phase systems is placed in circuit. As we have pointed out, this meter usually consists of two

elements combined under one cover and acting on a common armature.

When a service consisting of motor and lights is fed from the connection shown in Fig. 17, the proper registration of the energy passing is accomplished by using two non-inductive meters connected as shown in Fig. 31, Chap. VI, or a polyphase induction meter so designed as to have one of its elements connected in circuit with the teaser circuit as outlined diagrammatically Fig. 31, Chap. VI.

CHAPTER III.

Meter Selection—Requisites of a Good Meter—Commercial Considerations.

Considerations other than cost render the selection of the best meter a difficult task, owing to the various classes of service to be provided for. In commercial distributions of current we have incandescent lamps, arc lamps and motors to meter beside other forms of energy consumers, such as electric heaters, etc. Frequently all of these forms of translating devices are found in one installation, and it is desirable to meter them through one meter. The current may be direct or alternating, or both, and the various conditions that the meter has to meet will be treated separately.

First. Varying Voltage and Load.

If a constant load at a constant voltage always passed through the meter, its calibration would be a simple matter, but, in the majority of installations, the variation is between the limits of an eight c. p. lamp and the full capacity of the meter. The meter must record the true watts passing at all loads, and its accuracy on light loads is extremely important. It is seldom that a good meter cannot be relied upon to record its full load within one or two per cent. of its correct value, but this same meter may be 50 per cent. slow on light loads and fail to record at all on an eight c. p. lamp. In large systems of distribution the voltage remains very constant, but in outlying districts,

and in small plants with insufficient copper in the lines, the voltage often varies ten per cent. either way from its normal value. The meter must record accurately under these variations of voltage. Light load accuracy has a far reaching effect on the earning capacity of the plant, and is so important that it is taken up more fully in Chapter VIII.

Second. Varying Frequency.

Only in a few of the larger plants are the alternating generators operated in parallel, and in many of the smaller plants it is often the case that two circuits from different machines may vary ten per cent. in frequency, owing to different speeds of the generating units. Meters in service are often called upon to register at slightly different frequencies from the one they are designed for. This irregularity may also be caused by the varying frequency of a circuit caused by change of speed of the generating unit. The meter must record accurately under these conditions the total watts passing in the circuit, or fail to meet the requirements of commercial service.

Third. Power Factor.

When a circuit is inductive it is said to have a power factor or a ratio of the true to the apparent watts passing in the circuit. Many circuits are purely inductive, such as those feeding induction motors, but a single installation may have connected incandescent lamps, or non-inductive load, as well as arc lamps and motors. The power factor under these conditions can vary from .55 to unity. The meter is called upon to register accurately throughout this range. These conditions are not at all unusual, but are met in practice every day.

Fourth. Sine Wave Form.

The changes of direction of alterations of a current vary in intensity from positive to negative according to the sine law. The variation approaches the true sine wave, but many wave forms met in practice are jagged, peaked or flat. A meter for commercial use must fit any wave form; that is, record as accurately on one form as another.

Fifth. Short Circuits.

The effect of a short circuit on a meter is one that should be carefully determined. The instantaneous rush of current is great and creates a strong magnetic field which extends to the permanent magnets and tends to demagnetize them unless a shield is interposed between them. This shield may be of iron, but a closed secondary band is sometimes placed around the field coil which sets up a counter magnetic field when a short circuit takes place. Another effect of short circuit on meters where a disk or drum armature is used is to distort or bend the disk by the powerful momentary thrust exerted which acts exactly like a blow. This is prevented in some meters by evenly distributing the field coils in such a way as to balance this thrust.

Sixth. Permanency of Magnetic Drag.

If the meter stand successfully the short circuit test without affecting the permanence of the magnets, it is proof against immediate deterioration, but the action of time may still be detrimental. Some essentials, however, of correct form and mode of manufacture will be of service in judging the magnets. A very hard steel, usually an alloy of tungsten, is highly tempered and magnetized by contact with powerful electro magnets and partially demagnetized by weak alternating current magnetizations.

This process is repeated until the steel is brought to a state of permanent magnetization. This state of permanent magnetization has been determined by experiment, and each manufacturer knows from the quality of steel used just the balancing line where the magnets will not lose or gain in magnetism. Conditions of length and area and length of air gap affect permanence. The magnet should be long and the pole pieces of sufficient area to allow of a good distribution of the magnetic flux. The length of the air gap should be small, otherwise the magnetic flow is retarded and the magnet is unable to maintain permanently a flow across the gap.

Where the magnets have been forged, the manufacturer usually lets them set to assume their final shape. Even then the distance between the poles may change slightly and the accuracy of the meter be destroyed. Any meter, therefore, which combines long magnets, short air gap and permanently fixed pole pieces has an advantage over one lacking these points.

Seventh. Torque.

The torque of a meter is directly proportional to its efficiency as a motor. In other words, suppose between the shunt and field losses it takes ten watts to operate the meter. These ten watts are the input into the motor meter, and the efficiency of this motor meter will give the ratio of the torque exerted on the armature. A good meter, then, should be as highly efficient a motor as possible to enable the losses to be made as small as is compatible with efficiency.

When we consider the counter frictional torque of a meter, the value of having the current torque as large as possible is immediately apparent. The torque of a meter

is also its measure of ability to overcome friction, namely, if the ratio of frictional and current torque be 1 to 100, the doubling of the friction would only cause a loss of one per cent. additional, whereas, if the ratio were 1 to 10, an additional loss of ten per cent. would be experienced when the friction is doubled. Hence, the securing of as large a torque as possible, without too great energy losses, is a matter of careful design and of extreme importance.

Eighth. Friction and Friction Balancing.

The support of the armature and the dial train are the points of friction in a meter, and in many meters are balanced by an initial turning impulse imported to the armature. The turning impulse remains constant, but the frictional equivalent is continually varying, not only in one location, but for various locations of the meter. As this friction changes with wear, we find the meters creeping in some localities and very slow in others, owing to the varying degrees of vibration present. Many forms of friction balance are used, but none are perfect, and the true solution of the problem lies in reducing the counter frictional torque to a minimum and raising the current torque to a maximum, so that the error due to friction is inappreciable. In selecting a meter, therefore, a careful determination of this ratio is all important.

Ninth. Energy Losses.

Work cannot be done without consumption of energy, and a balancing ratio between the energy needed and the torque desired must be reached in the determination of the allowable losses in the meter.

The loss in the potential circuit ranges from 1½ to 15 watts in different makes of meters. Only a part of the

energy is available for useful work; the remainder is given off in heat. The field losses vary with the load, but should never exceed one per cent. of the rated capacity of the meter on full load.

Large losses in the shunt and field circuits are, in poorly designed meters, not compensated for by a resulting large torque, or in other words, the *efficiency* of the motor meter is very low. The determination of this *efficiency* is easily made by measuring the pull of the disk by means of a sensitive spring balance when a given load is on the meter. The reduction of the watt losses of the meter to their mechanical equivalent at the point of attachment of the spring balance will give the ratio between the actual work done and the energy consumed. The meter possessing the *highest efficiency* and largest torque has a much better chance of remaining permanently accurate, provided its counter frictional torque is lower than in one that is less powerful.

Tenth. Armature Support and Vibration.

The critical point in the permanence of the constants of a meter is the insurance of a permanent non-frictional support for the armature. Much time and money have been expended in this development, and the two outcomes are a highly polished jewel, on which runs the hardened steel point of the armature spindle, and magnetic flotation of the armature.

The jewel and hardened steel point can hardly be called a permanent solution of the problem, as, under certain conditions, the jewel wears and breaks down very rapidly, destroying at the same time the smoothness of the steel shaft.

The causes of jewels breaking down are vibration and dust. It is almost impossible to eliminate vibration of the

meter support in some locations. The passing of cars and wagons, and heavy jars given to the building, jolt the meter, causing the armature shaft to strike a blow on the jewel which frequently cracks and very quickly destroys its polished surface. On alternating current circuits the process is even more disastrous in its final results. The slight vibration or tremor in the armature drum or disk imparted to it by the shunt winding, which is always in circuit, hammers the jewel at the rate of the alternations of the service circuit. The millions of minute blows gradually destroy the smoothness of the jewel and it finally breaks down. Magnetic flotation of the armature not only cures this evil, but reduces the initial friction of the meter to a large extent. The armature is floated in space by means of a permanent magnetic system, and any vibration which produces a lateral thrust has no effect on the meter. A meter possessing magnetic flotation of the armature and fulfilling the previous conditions, if it meet the requirements of the service, comes nearer the ideal conditions than any other.

The presence of dust or grit in the meter grinds the polish off the jewel and quickly wears it out. In magnetically floated armature guides this dust would be even more disastrous.

Eleventh. Air Tight.

To keep out dust, insects, acid fumes and all foreign matter the meter must be air-tight. The carelessness of meter manufacturers in this respect has been appalling, but the responsibility for this defect rests ultimately upon the meter buyer, as he should insist on this point.

In order that the meter may retain its calibration it must have the same conditions present in service that it had when

installed, and the exclusion of all matter which can in any way change the relation of the different elements to each other must be insured.

Twelfth. Temperature Co-Efficient.

The temperature co-efficient should be unity through a wide range. The range of temperature over which meters work during a year's service is as high as 100°. Meters tested hot and cold often show as much as five per cent. difference in their reading, owing to the different resistance of the windings at different temperatures.

Thirteenth. Insulation.

The failure of many meters is caused by defective insulation. A meter is easily tested for insulation, and should be rejected unless it can show several megohms between the windings and meter frames.

Fourteenth. Mechanical Features.

An eminent engineer once said that if a machine look right it is almost sure to be right in design, probably drawing this conclusion from a sense of the fitness of things. All the electrical conditions may be successfully met by a meter, but its mechanical design may be so poor as to make it worthless. Besides the elimination of friction of the moving parts, it is an important consideration that the general get-up of the meter should be pleasing and carefully worked out. Meters receive a great deal of handling, and frequently rough handling. The mechanical details need not be elaborated, but the proper construction of the meter frame and parts should be worked out along the lines of strength and rigidity rather than lightness.

The commercial problems involved in meter selection are complicated by reason of the great variety of service furnished. Following close upon the determination of a meter's electrical and mechanical excellence come the questions of first cost and operation, which vary with the kind of service to be metered. The different classes of service which may be met in practice, generated and sold by one company, are as follows:

1. Plain direct current two-wire systems of 115, 220 or 500 volts.

2. Three-wire direct current systems of 115–230 and 220–440 volts.

3. A combination of either one or two, with a single-phase two-wiring alternating current system.

4. A combination of either one or two, with a polyphase system.

5. Plain single or polyphase distributions for light and power.

6. Series arc systems in conjunction with any of the above.

Many more combinations might be given, but the above are the most common and will serve as illustrations. To meet the first case a two-wire direct current meter of either the chemical or motor type is what is needed. The most extensively used meters for this service in America have been the Edison chemical meter and the Thomson recording wattmeter. The chemical meter is rapidly passing into disuse. In principle it is an ampere hour-meter possessing many points of value, but, owing to the immense amount of work connected with its operation, it has been steadily losing ground to the Thomson or commutated type of meter. For many years the Edison chemical meter has been the mainstay of direct current

stations, and, when carefully operated, furnished a very accurate register; in fact, in many instances a far more accurate record can be obtained with it than with any mechanical meter. An incident is recalled within the writer's experience where the vibration was so great that special screw clips were designed to hold the bottles in circuit, the conditions being such that any mechanical meter would have been ruined in less than half a day.

The Thomson and Duncan commutated meters are practically, at the present writing, the only direct current meters in use in America, although in the near future there promise to be other forms. At the present there are only two selections to make, either the chemical or commutated types. Modern practice has decided in favor of the commutated type.

The second case falls under the same limitations as the first and may be dismissed with the same considerations.

For the sake of simplification we will confine ourselves in the selection of the best meter to fulfill the conditions of the third class to motor types of meters.

Here we have a varied class of service, direct and alternating current, and we must bear in mind that it is easier and better to have but one type of meter in service.

Let us assume, as one phase of case three, a low tension Edison net work with an outlying district fed by alternating current. Then, on all sides where the two districts meet there will be lapping over of the direct and alternating service. If two types of meters be used, which are not interchangeable, the meter service is not as flexible as it would otherwise be. It would also necessitate the carrying of a much larger stock of meters to meet all demands. Again, the service to any installation could not be changed from direct to alternating or vice versa without changing

the meter as well. The advantages in using a meter common to both systems may be summed up as follows:

1. Flexibility of meter service.
2. Carrying of a smaller stock.
3. Simplification in the repair and testing departments.
4. The same quality of meter service to all customers.

Any form of meter, therefore, which will operate with equal accuracy on direct and alternating current without any change in calibration would, other considerations being equal, be the proper one to use.

When the problem is further complicated by having a polyphase system to meter in combination with a direct current system, conditions arise which have to be carefully considered. If a meter having an armature and commutator is used for the direct current it will take two or more meters per installation to meter an unbalanced polyphase service, so that the first cost of meters must be taken into consideration, that is, whether it is cheaper to install two meters or one polyphase induction meter. Other considerations also enter. The consumer in general does not understand why two meters should be put in to register a single service, and no amount of explanation will disabuse his mind of the idea that the company is getting the better of him. Again, the maintenance and repairs on two meters are double that of one and will add to the cost of operating the meter department. These considerations outweigh those advanced for the use of one type of meter, and it is preferable, in this case, to use two types of meters. In case five, where only one class of service is given, namely, a single or polyphase distribution, the selection of a meter is largely controlled by local preference. There are a number of meters which can be used with equal success, questions of first cost, durability and small maintenance are deciding

factors, and, as the service is not mixed, it is best practice to use a single meter per installation. It is frequently the case that a central station has no choice in the selection of its meters; under such conditions it is hard to work out a satisfactory system unless the meter happens to be a good one.

If the meter selected comply with both the electrical and commercial requirements its successful operation should be assured with ordinary care.

CHAPTER IV.

Torque and Friction.

The designing of a meter for permanent commercial accuracy involves a great many serious problems. In Chapter III we have alluded to the principal qualifications to be fulfilled by a good meter. The subject of torque was treated briefly, but its true significance in meter design needs fuller elaboration.

The word "torque" is used to express the force with which a rotating body tends to revolve, and is usually expressed in foot pounds. Counter torque is a force acting in opposition to torque; thus, the friction of a moving body may be expressed as counter torque, the overcoming of which consumes a certain proportion of the torque of the rotating body. In a meter the torque is a minute fraction of the foot pound unit, and the counter torque or friction a smaller quantity still. If a half dozen different makes of recording wattmeters be set up and tested when new, a very slight difference may be noticed in their readings on full and medium loads, but very decided differences are recorded on light loads from five per cent. and under of the full load capacity. In other words, each meter has a different ratio between the force impelling it forward and the friction of the moving parts holding it back. The friction in each meter may vary widely, and the impelling force or torque may do the same. Consequently, there is a different ratio between friction and torque for each individual meter.

The continued accuracy of any meter depends primarily on preserving permanently the ratio between torque and counter-frictional torque. The variable quantity in this ratio is the counter-frictional torque; hence, the torque should be so large in proportion that a doubling or trebling of the frictional torque would have no appreciable effect on the accuracy of the meter. For example, suppose the ratio existing in a given meter on a given load be 1 to 100, then, by doubling the friction, the ratio becomes 2 to 100. In the first ratio the error would be one per cent., in the second, two per cent. On the contrary, if the first ratio on the same load were 1 to 10, the doubling of the friction would make an error of 20 per cent. in the reading of the meter instead of two per cent. as in the second ratio. Carrying on this process, multiplying each friction by ten in both ratios gives a ten per cent. error in the first one and a complete stoppage of the meter in the second. If the frictional counter torque were not of a negative character the increasing of this friction in the second ratio above ten would result in a reversal of the meter. In speaking of the frictional torque, therefore, we have to think of it as a negative torque, which is to be subtracted from the current torque, but cannot exert its influence to revolve the meter in an opposite direction.

The current torque remains constant for a given load on the meter, but necessarily varies with the load; hence, if the ratio be 1 to 10 on ten per cent. of the capacity of the meter, it becomes 1 to 100 on full load. Therefore, the percentage by which the meter runs slow on full load may be read as a multiplier of the frictional torque; for instance, eight per cent. slow means an increase of friction of eight times the original amount. It is assumed, in this statement, that the meter ran properly originally and became

slow through increase in friction. Meters can run slow from other causes, but these causes are not at present under discussion.

In order to present more clearly the ratio of current torque and counter-frictional torque, a meter of five amperes capacity is selected for illustration.

For the sake of analysis the friction-torque ratio of the meter is assumed to be as stated in the second column:

Load.		Friction-Torque Ratio.	Per Cent. Slow.
10 lamps	= 100%	1–50	2%
5 "	= 50%	1–25	4%
2½ "	= 25%	1–12½	8%
2 "	= 20%	1–10	10%
1 "	= 10%	1– 5	20%
8 c. p. lamp	= 5%	1– 2½	40%
Stopped	= 2%	1– 1	100%

In order to avoid such a poor showing as the above, a friction compensator is introduced which, theoretically, compensates for the friction and enables the meter to run correctly under all loads. Since this friction compensator is not automatic in its operation, that is, does not increase as the friction increases, it affords only imperfect relief, as the increasing of the frictional torque by ten would stop the meter on 20 per cent. of its full load.

The remedy lies in increasing the ratio. If the friction remain the same, the doubling of the torque in the foregoing table would result in the following:

Load.	Friction-Torque.	Per Cent. Slow.
Full	1–100	1%
Half	1– 50	2%
Quarter	1– 25	4%
20%	1– 20	5%
10%	1– 10	10%
5%	1– 5	20%
2%	1– 2	50%

Increasing the friction by ten in this instance would stop the meter on ten per cent. of its load, and make it ten per cent. slow on full load instead of 20 per cent. slow on full load as under the conditions assumed for the previous table.

Carrying out this principle one could get a meter that for all commercial considerations would be correct through all ranges of load. Two things must be done to accomplish this result, namely, increase the torque and reduce the friction. The most economic course is to eliminate friction, as this keeps down the power consumption of the meter. When the frictional equivalent is reduced to its minimum for a given form of construction, the friction-torque ratio at full load for any meter should not be less than 1:400. This ratio with no friction compensator gives a two and one-half per cent. error on ten per cent. of full load, which is close enough for commercial use; it would mean an error of 1.2 watts with one light burning on a five ampere meter.

It is evident from the foregoing that there is an economic limit to the increase of the torque of a meter to obtain greater accuracy. When this increase in torque is directly proportional to the increase in current necessary to produce it, it is possible to consume more power in obtaining

extreme accuracy than the amount of power lost through inaccuracy. If the ratio 1:400 were doubled, making it 1:800, and this entailed increasing the power consumption of the meter by three watts, nothing would be gained; on the contrary, a loss would be sustained of 1.8 watts on any load the meter registered.

By assuming a fixed frictional equivalent, the economical torque of any meter can be worked out. In all forms of motor meters the design should be such that the maximum torque should be obtained for a given input in current. If all meter losses in a given case amount to five watts, the meter should have a resultant torque approaching as closely as possible its mechanical equivalent, or about $\frac{1}{150}$ horse-power. As a rule meters are very inefficient, considered as motors, and cannot be otherwise from their construction.

In a 500-wattmeter, assume that the friction has been reduced to its lowest possible limit, and that the meter consumes at full load six watts in its shunt and field coils. With this consumption of energy, also assume the friction-torque ratio to be 1:100. The meter, if uncompensated, would lose one per cent., or five watts, at full load from friction. If eight watts were consumed by the meter and the torque thereby increased by $33\frac{1}{3}$ per cent., the friction-torque ratio would be $1:133\frac{1}{3}$, and the error at full load three and three-fourths watts. If nine watts were consumed by the meter and the torque thereby increased by 50 per cent., the friction-torque ratio would be 1:150, and the error at full load would be three and one-third watts. The net gain, therefore, would be only one-third watt, so this ratio of 1:150 could be assumed to be about the point of economical balance, beyond which there would be no gain in further increasing the torque at the expense of

further loss of power. Where the friction is an absolute fixed quantity, the friction-torque ratio of any given meter may be worked out in the same way.

A graphic method of determining the friction-torque ratio of a given meter is as follows: Adjust the friction compensator on no load so that the meter is just balanced; that is, so that it will creep under the slightest vibration. When this is done, turn on the full capacity of the meter and take its speed under full load; then remove the friction compensator and note the difference in the speed of the meter under the same load. The percentage of slowness will be inversely proportional to the friction-torque ratio; thus, two per cent. would mean 1:50; one per cent., 1:100; and so on. When the friction-torque ratio is determined, it is very easy to figure out the gain or loss that the consumption of additional power to increase the torque would entail.

Meters with ratios under 1:400 are the rule rather than the exception, but their frictional equivalent is such that it is impossible to better them. Many meters fail in commercial service by having an unstable frictional equivalent, through faulty mechanical design or improper protection of the revolving parts from foreign matter.

The correct end of all meter design is towards an unchanging frictional equivalent of infinitesimal amount and the largest possible economic torque determined by the rules laid down above. Friction compensators should be discarded where possible.

Meters vary in the amount of power required in their potential circuits, and, also, in the amount used in the field windings. The values of these combined amounts should be taken at full load of the meter and a tabulated set of friction-torque ratios put down. The ratio for a given loss

of power can be found by ascertaining the loss in registration at full load of the meter caused by the friction, and compensating for this by giving the meter more torque at an increased expenditure of energy. From the tabulated values it is a simple matter to select a friction-torque ratio that cannot be increased unless more energy is expended than will be saved by the increased accuracy obtained.

In the following tables three different amounts of power loss are assumed in relation with the same friction-torque ratios; the balancing ratios obtained represent the correct design of the meter to obtain the highest economy under any one of the given conditions.

TABLE I

Ratio	Consumption in Watts in Meter at Full Load.	Correct Watts for Balancing Ratio.	True Balancing Ratio.
1– 50	2	5	1– 125 app.
1– 100	2	4	1– 200
1– 200	2	3¼	1– 325
1– 400	2	2¾	1– 550
1– 800	2	2½	1–1000

1–1000 The highest economic balance at 2½ watts consumption of current.

TABLE II

1– 50	4	8	1–100 app.
1–100	4	6	1–150
1–200	4	5½	1–275
1–400	4	5	1–500

1–500 The highest economic balance at 5 watts consumption of current.

TABLE III

1– 50	6	11	1– 90 app.
1–100	6	9	1–150
1–200	6	7¾	1–250

1–250 Approximate highest economic balance at 7¾ watts consumption of current.

These tables show that for different values of the frictional equivalent the amount of energy necessary to produce the best results varies accordingly. For example, in Table I the ratio 1–50 with 2 watts consumption of current is an inefficient ratio; the true ratio should be 1:125 with 5 watts consumption of current.

In Table II the ratio 1–50 shows that it should be 1–100 with 8 watts consumed instead of 4. As the energy torque remains the same and the friction decreases, a ratio is reached wherein no change either way can be made to make the meter more efficient. In Table I this ratio is 1–1000 with 2½ watts consumption of energy.

As the consumption of energy increases, as shown in Tables II and III, the ratios diminish in direct proportion. If a ratio of 1–50 consume 10 watts, it is balanced, and the meter cannot be improved by increasing the watt consumption.

Tables can be made of various watt losses of different meters, and economic balance of any meter obtained after its ratio is found.

The foregoing tables will be useful for designers and also to the central station in the selection of meters. It is assumed in the foregoing that the frictional equivalent is uncompensated, but, as the majority of manufacturers try to compensate the frictional losses of their meters, the ratio of almost all meters on the market can be obtained as outlined without much difficulty.

The Stanley meter is uncompensated, the frictional equivalent being so slight that it has a very large ratio. The ratio can be determined on this meter by noting the number of watts on which it starts. This per cent. of the full load capacity would determine the ratio of the meter with reasonable accuracy.

Too much stress connot be laid on low and permanent frictional equivalent. If these elements can be fixed it is an easy matter to build an accurate meter for all loads.

It is customary among meter manufacturers to maintain the torque for the same percentage of load constant through various sizes of meters. Thus a five ampere meter may run at the rate of one revolution in four seconds on full load, and a 100 ampere meter run at the same rate on full load.

The registration on the dials is corrected either by multiplying by a constant or changing the ratio between the revolving armature and the registering train.

A 100 ampere meter, therefore, with a ratio of 1–50 would have a ratio of 1 to 5 on 20 lights or 20 per cent. slow on this load on two per cent. of its capacity it would stop, that is, on four lights. Of course, the friction is compensated for as far as possible, but any increase in friction makes the above conditions more aggravated.

Any meter therefore with such a ratio is absolutely unreliable and can never be made to run correctly. The central station is the loser.

A different set of tables must, therefore, be made up for each capacity of meter, and its balancing ratio obtained to determine just where it stands with regard to accuracy.

If a 100 ampere meter with a ratio of 1–50 be installed and the friction compensated for, it may run approximately correct for a short period, but the friction is liable to treble or quadruple itself at any time, and the compensator will only take care of the original friction value.

A curve of the meter's running can be plotted showing the per cent. slow at various increases in friction.

If we take a meter of 500 watts capacity as a base from which to deduct different values for friction and torque, we arrive at ratios given in the following tables.

We will suppose that, if a certain torque be obtained by a given input in watts in the meter, a larger or smaller input will increase or decrease the torque in direct proportion.

If the meter have no compensation for its friction, it will run at various percentages slow according to the load; thus a meter two per cent. slow on full load will be four per cent. on half load and so on.

TABLE I

Friction.	Torque.	Watt Loss in Meter.	Ratio.	Watt Loss due to Friction.	Total Losses in Meter and by Friction	% Slow.
.05	50	10	1–1000	½	10½	1–10 of 1%
.1	50	10	1– 500	1	11	1/5 of 1%
.2	50	10	1– 250	2	12	2/5 of 1%
.4	50	10	1– 125	4	14	4/5 of 1%
1	50	10	1– 50	10	20	2%
2	50	10	1– 25	20	30	4%
4	50	10	1– 12½	40	50	8%
5	50	10	1– 10	50	60	10%
10	50	10	1– 5	100	110	20%
25	50	10	1– 2	250	260	50%
50	50	10	1– 1	500	510	stopped.

TABLE II (Doubling the Torque by Doubling Input.)

.05	100	20	1–2000	¼	20¼	1/20 of 1%
.1	100	20	1–1000	½	20½	1/10 of 1%
.2	100	20	1– 500	1	21	1/5 of 1%
.4	100	20	1– 250	2	22	2/5 of 1%
1	100	20	1– 100	5	25	1%
2	100	20	1– 50	10	30	2%
4	100	20	1– 25	20	40	4%
5	100	20	1– 20	25	45	5%
10	100	20	1– 10	50	70	10%
25	100	20	1– 4	125	145	5%
50	100	20	1– 2	250	270	50%

TABLE III

Friction.	Torque.	Watt Loss in Meter.	Ratio.	Watt Loss due to Friction.	Total Losses in Meter.	% Slow.
.001	10	2	1–400	1¼	3¼	¼ of 1%
.05	10	2	1–200	2½	4½	½ of 1%
.1	10	2	1–100	5	7	1%
.2	10	2	1– 50	10	12	2%
.4	10	2	1– 25	20	22	4%
1	10	2	1– 10	50	52	10%
2	10	2	1– 5	100	102	20%
4	10	2	1– 2½	200	202	40%
5	10	2	1– 2	250	252	50%
10	10	2	1– 1	500	502	stopped.

TABLE IV

.001	20	4	1–800	.62½	4.62½	⅛ of 1%
.05	20	4	1–400	1¼	5¼	¼ of 1%
.1	20	4	1–200	2½	6½	½ of 1%
.2	20	4	1–100	5	9	1%
.4	20	4	1– 50	10	14	2%
1	20	4	1– 20	25	29	5%
2	20	4	1– 10	50	54	10%
4	20	4	1– 5	100	104	20%
5	20	4	1– 4	125	129	25%
10	20	4	1– 2	250	254	50%
20	20	4	1– 1	500	504	stopped.

In the Tables I, II, III and IV we have meters consuming 2, 4, 10, 20 watts respectively. These meters are supposed to operate at the same efficiency per watt, that is, have the same torque per watt.

Various friction values are assumed, the unit of friction being taken as some proportion of the torque unit.

In Table I a meter having a friction value of .05 and torque value of 50 with a watt consumption of 10 has a ratio of 1–1000, and the total meter losses are 10½ watts.

The same meter, Table II, with double the torque and double the watt input has a ratio of 1–2000 and total meter losses on full load of 20½ watts.

It is seen at a glance that the lower torque meter Table 1 is the more efficient.

In Table III a low torque meter having the same frictional value with 2 watts input has total watt losses on full load of 4½.

These tables enable one to ascertain the correct watt input of a meter having a given frictional equivalent for the most economical running.

In these tables the watt losses at full load are given for various friction values, and it is seen that the low torque meters are the most economical on low friction values and the high torque meters on large friction values. In other words, every meter having a given frictional equivalent has a balancing ratio at which it will operate most economically and correctly.

Table I from .05 to .2 frictional equivalents, we find by comparison that Table III is far more economical, while for values from .2 to 10, Table I is the best.

Like comparison can be made for various values in the different tables.

These tables are calculated for the purpose of showing the losses due to uncompensated friction. As nearly all meters are compensated, these tables do not apply when the meter is correct, but should the friction equivalent become increased while in service, the losses set forth would occur.

The lines to be pursued in obtaining a correct meter are the reducing of the frictional equivalent to its lowest permanent value and the designing of the meter electrically for its greatest efficiency per watt input.

In other words, if a meter consume four watts on full load and have a torque value of 20, the frictional equivalent must be at least as low as .4 of this amount, or it becomes more economical to consume more than ·4 watts to obtain a larger torque. The ratio must not fall below 1–50. If a ratio between torque and friction of 1–100 be obtained, the wattage can be reduced to 2 with more economical results as shown (Table III).

With high friction values we get better results by using more watt input. For instance, with a ratio 1–10 (Table III) we get 52 watts loss; the same friction value (Table IV) gives us a ratio 1–20, watt loss 29, while in Table 1 we have a ratio 1–50, watt loss 20. The same friction value, Table II, gives a ratio 1–100, watt loss 25, showing that ratio 1–50, watt loss 20, is the balancing ratio.

In the foregoing it is assumed that the central station, not the consumer, pays for the loss in the meters.

CHAPTER V.

The Edison Chemical Meter.

Almost from the inception of electric lighting the Edison chemical meter has been used for the metering of direct currents. In theory it is an ampere hour meter, and with proper manipulation and care it proves a wonderfully accurate meter in service.

If two plates of zinc be immersed in a solution of sulphate of zinc and a current passed from one plate to the other through the solution, zinc is carried over from the

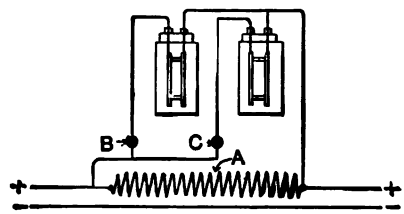


FIG. 18

positive plate and deposited on the negative in direct proportion to the amount of current flowing. This principle is utilized in the Edison chemical meter.

In a solution of zinc sulphate having a density 1.11, one ampere of current will deposit 1.224 grams of zinc per hour. This rate of deposit would necessitate having plates weighing a ton to register large amounts of current. This difficulty is surmounted by using a shunt of low resistance and allowing only a small fraction of the current to be used in registering, the amperes flowing in the circuit. Fig. 18

represents, diagrammatically, the arrangement of the meter for the two-wire system. It is observed that there are two bottles each containing two plates held at a fixed distance from each other by rubber bolts and spacers. Two bottles instead of one are used to serve as a check on each other.

A is the low resistance German silver shunt, *B* and *C* are spools on which is wound copper wire of comparatively high resistance. In the 12 light meter the shunt has approximately .02 ohm resistance and the bottle circuit 19.50 ohms, of which the spool has about 16.50 ohms and the bottle 3 ohms, making a relation of 1 to 975 be-

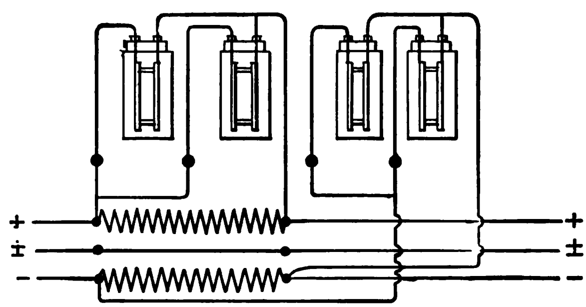


FIG. 19.

tween the shunt and bottle. From this relation a constant is worked out for the meter to determine the amount of money one grain or fraction thereof represents. This constant varies with the voltage of the circuit employed if the service be charged for by watt-hours.

In the three-wire meter, Fig. 19, a shunt is inserted in each outside leg, making simply two two-wire meters under the same cover. The meter is made in a number of commercial sizes, and these can be made of longer recording capacity by increasing the resistance of the bottle circuit.

The zinc plates are mounted on hard copper rods threaded into the top end. The glass bottles resemble fruit jars with two holes in the cover for the extended rods. Of late years a large cork was used instead of the glass top and considerable time saved in assembling the cells. The whole meter was mounted in a well seasoned wooden box having a sheet iron door with a shelf provided midway in the meter for the reception of the bottles. The low resistance shunts were contained in the lower part of the meter. The hard copper rods were pushed into hard copper spring contact clips for connecting them in circuit. In cold climates a lamp in series with a thermostat is placed in the meter compartment for furnishing heat if the temperature falls near freezing point. The temperature coefficient of the meter is preserved at unity by winding the resistance spools with copper wire, as copper increases in resistance and German silver decreases as they grow warmer. The solution decreases in resistance as it grows warmer, so the copper spools become a balancing factor between the German silver shunt and the solution. The fall of potential across the shunts is so slight as to make the energy losses of the meter inappreciable; the nature of the loss being the same as a line loss, and not a consumption of additional energy.

By following the meter through its practical operation in the meter department its different features will be clearly brought out. The zinc plates must be chemically pure, or, otherwise, battery action will be set up in the cell and a counter electromotive force generated which will destroy the accuracy of the register.

When the plates are received from the makers they are rough stampings with the hard copper rods screwed into their ends. The first operation is to polish them smoothly

on a sand wheel and then amalgamate them in mercury. The surplus mercury is removed by a revolving brush. The finished plate is smooth and silvery in appearance. The mercury has the effect of rendering the plate active and eats its way inward as the zinc is deposited from one plate to the other. The bare zinc plate unmalgamated seems to possess a sort of resisting property to free action which hinders it from being deposited at a uniform rate. The joint between the zinc plate and copper rod should be painted with black asphaltum paint to keep the mercury from eating away the copper and allowing the rod to become loose in the joint. This paint is put on before the plate is amalgamated. When ready to be weighed it is tested across the joint with a galvanometer to insure the presence of a perfect electrical joint. It is found that, after the plates have been in service for some time, this joint frequently becomes defective, and a resistance is thereby added to the bottle circuit which makes the meter register less than it should. Analytical balances of the greatest delicacy are used in weighing the plates and the plates are weighed to within 5 milligrams. Two methods of weighing are in use; the single and double system. As only one plate loses weight, the positive one, the single method of weighing records its weight on suitable slips, and when the plate comes back at the end of the month its lost weight is proportional to the amount of current used. If the plate be reversed in the meter, the weighed plate gains in weight instead of losing. The gain or loss represents the amount of current used. The double weighing system weighs both positive and negative plates on a double rider balance, the net difference in weight being recorded. When the plates are returned the net difference is again noted and the loss recorded on the slip.

After the plates are weighed by one operator they should be check weighed to eliminate errors by another operator. Each plate is given a number and letter written on the back of the plate itself, so as to identify it on its return to the meter department. From the weighing bench the plates are taken to be assembled, which consists of bolting positive and negative together, and separating them by insulating spacers of a fixed width. The plates are reground and used over and over again until they wear out. The preparation of the solution must be carefully done, and all the ingredients must be chemically pure. Distilled water and sulphate of zinc are the two ingredients, and these are mixed in solution to a density of 1.11 actual. After mixing, the solution is filtered to remove any foreign particles that may have fallen into it. The bottles are washed clean, and the assembled plates put in with the solution covering them for about half an inch. When a large number of bottles are handled daily, special tanks of porcelain or glass should be arranged to hold the solution, and the bottles filled from them by a flexible hose with faucet attached.

A given number of meters should be read each day, and they should be listed according to location and a route list given to the man changing the bottles.

The great secret of success in the metering of current in this way lies in the exercise of extreme care in each operation. Carelessness in any one part of the work affects the whole system. In the installation of the bottles in the meter care must be taken to place the positive plate to the positive clip of the meter, otherwise reversed plates will be the result. It is the practice in some plants to put one bottle in reversed and one bottle the right way and take the average of the sum of the readings, but this method is

open to objection if the bottles become "smutted" from excessive load.

The "smutting" of the plates is caused by the too rapid deposition of the zinc, and, if carried on too long, the plates are bridged across with black bridges resembling coke. This short circuiting of the plates shunts them, and makes them register less than they should. When a meter is found to smut badly, even if it do not short circuit, the bottles should be renewed oftener or a larger meter put in. It has been found, by a careful series of tests by the author, that a heavy smutting increases the registration by about 10 per cent., and a short circuit decreases the registration by a varying quantity dependent on how many bridges have been built up between the two plates. It was found that, where there was excessive vibration, the bottles gradually crept out of the clips and ceased to register. Again, it was found that verdigris and dirt frequently introduced a resistance in circuit which kept the meters from registering all that they should. Considerations of this nature led to the adoption of a cast brass clip in which holes were provided for the reception of the copper rod terminals of the cells. A set screw was provided for setting the rods up hard in the hole, and it was impossible to get them loose. The grinding movement of the screw on the rod insured a good contact. The great improvement in the registration of the meters led to their adoption for the entire system of a large plant. It was the watching of every minute detail and the careful handling of this meter that made it a commercial possibility for 20 years.

The great drawback to the meter is that it cannot be read by the consumer. The consumer was, so he thought, absolutely at the mercy of the company furnishing current,

and he could seldom follow the process of measuring the current intelligently when the method was explained to him. Another great drawback to the meter is that it has no rate of measurement from which to determine its accuracy. In other words, if a reading failed for one month owing to some accident, the only recourse was to take a check reading and estimate the bill. In a mechanical meter, if the reading be disputed, a test can be made of the meter and a determination made of its accuracy, from which a bill can be checked up with a fair amount of precision. On the other hand, the chemical meter could not "run slow" for more than a month, as it was practically a new meter after each renewal.

After the bottles have stood for a month, even if no current be used, a slight oxidation takes place which increases the weight of the plate slightly.

When the bottles are taken apart, if the single plate method of weighing be used, the plates are dipped for a moment in dilute sulphuric acid and quickly rinsed. This removes the slight over-weight caused by oxidation. When the double plate method of weighing is used, the oxidation on the negative and positive plates cancel each other, so no dipping is required.

The relation between the shunt and bottle circuits rarely changes, and when it does it is nearly always due to an open circuit in the spool. The infinitesimal difference of potential between the adjacent coils in the spools renders a short circuit in them practically out of the question. However, the precaution is taken to boil the spools in paraffine.

The labor of maintaining the meters is excessive, and the details, when a large number of meters are operated, cumbersome.

The chemical meter is passing out of use. Its commercial accuracy is equal to many mechanical meters, but there are advantages in the mechanical type which offset some of the advantages which the chemical meters possess over them.

If this description of the chemical meter were likely to prove other than of historical interest, many interesting details of operation and arrangement of the meter department would be gone into, in the belief that they might prove of service. The meter has been barely sketched for the purpose of illustrating a type which so long held first place in the meter world, but which has passed its day of usefulness. Some of the requisites of a good meter are fulfilled in this meter. Its light load accuracy is very good on small sizes of meters, but not on large sizes, owing to the modifying effects of increased oxidation due to large plates.

Vibration does not alter the accuracy of the meter if the copper rods be held firmly in contact by set screws. As the meter's accuracy is altogether dependent on the continued care and accuracy of many operations, individual inaccuracies are not as likely to occur as for a whole system to become deranged by some chemical impurity in the solution or some such similar cause.

The meter is not adapted to the measurement of alternating current, but can measure in ampere hours any constant voltage direct current by obtaining the proper constant for reduction to watt hours.

CHAPTER VI.

The Thomson Recording Wattmeter.

The Thomson recording wattmeter is one of the most widely used meters in America, up to the present time. Its extended use has been in great measure due to its being practically the only meter on the market for direct current, and to its further quality of adaptability to all forms of service.

Its ability to register either alternating or direct current, whether the former be inductive or non-inductive, without change of calibration makes it especially suitable to the needs of central stations furnishing different kinds of current.

In principle, the meter is a modification of a Siemens' dynamometer, the stationary coils of which are energized by the current flowing, and the movable coils proportionately to the potential of the circuit in which the meter is inserted. There is no iron employed in the shunt or series field coils, the shunt coil or armature being wound drum fashion over a non-magnetic skeleton support and provided with commutator and brushes.

The operation of the dynamometer then becomes that of a simple motor. The current flowing energizes the fields and the potential of the circuit, the shunt field coil and armature.

It is evident that the torque of the armature will be proportional to the product of the field current by the E. M. F. of the circuit or the watts passing through the meter. If

the potential be constant, the meter may be used as a recording ammeter, as the torque of the armature then varies as the amperes. If the current be constant and the voltage be variable, the meter may be used as a recording voltmeter.

The construction of the meter has been carefully worked out mechanically. The armature spindle is supported on a spring seated removable jewel and the shaft end provided with a hardened steel removable point, which may be renewed when the jewel becomes defective and needs replacing. Secured to the shaft just above the jewel bearing is a copper disk revolving between the poles of permanent magnets, which act in the usual manner to furnish a brake proportional to the torque on the armature.

The commutator is made of silver, highly polished, and the flexible copper brushes bearing on it are silver tipped. Silver was chosen for this purpose after a long series of experiments with other metals, owing to its not forming a high resistance oxidized film over its surface when exposed to the air for extended periods. The usual worm gear actuates the dial train which records in watt hours, modified by whatever constant the meter carries. At constant 1 the meter records a watt hour for every revolution of the armature.

In two-wire meters the field coils are placed one on each side of the armature and connected in series; in three-wire meters the same position is occupied, but one coil is connected in each side of the circuit, the armature acting in common for both fields. Either field and the armature constitute individual recording elements which will act independently of the other field. Hence, any unbalancing of the regular three-wire system does not effect the accuracy of the meter. If the voltage on both sides of the system be the same, the register will be true watts; if

different, the error will be proportional to the difference existing. As the same error exists if the armature be fed from across the two outside legs, it is manifestly no gain to feed the meter in this way.

In series with the armature is a resistance coil to regulate the flow of current in the potential circuit, and also to reduce the fall of potential between the armature coils and commutator segments. The initial friction of the meter is compensated by a coil in series with the armature circuit; this coil is wound parallel to the field windings and placed inside of one of them, it is immaterial which. The coil is so proportioned as to overcome in great measure the friction of the moving parts, enabling the meter to register more accurately on light loads. The torque exerted by this auxiliary coil is about two per cent. of the full load torque of the meter. Care must be taken in installing the meter to secure it as far as possible from vibration, otherwise the meter will creep, unless the starting coil be adjusted to suit the local conditions.

Later types have an adjustable starting coil. This adjustable starting coil is wound with a great many more turns than the permanent coil used in older types. It is carried in a little frame which is movable in and out of the field coil by means of a screw. When the meter is installed, the local conditions of vibration are noted and the auxiliary starting coil so adjusted as just to balance the frictional torque of the meter in its present position without allowing it to "creep." Should the jewel become slightly defective after several months' use, the starting coil can be reset to overcome this additional friction of the meter. This arrangement is an improvement over the old method of having a permanent additional torque imparted to the meter no matter what the conditions incident to its location.

When the meter is used on alternating current circuits, we may think of its action by considering the circuit for an instant of time. This was gone into fully in Chapter II, and need not be further elaborated, but, as the true power

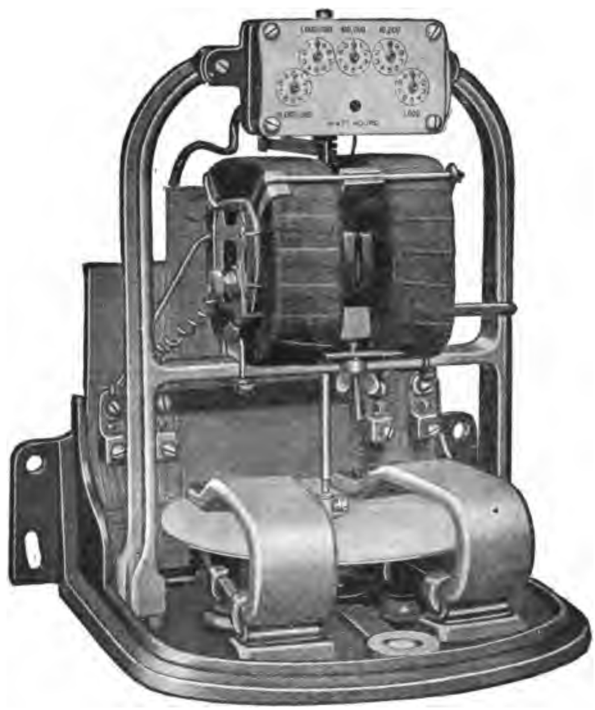


FIG. 21.

in an alternating circuit for any instant of time is the product of the instantaneous values of current and E. M. F., the meter registers as accurately on inductive as non-inductive load.

To fulfil the demands of service the meter is manufactured in a great variety of sizes and types of "low efficiency" and "high efficiency," the latter type succeeding the former in general commercial use, owing to its greater accuracy on light loads and lower watt consumption in the potential circuit. The potential circuit of the high efficiency type in the 115–230 volt commercial sizes for light consumes about 4 watts of energy, the 230–500 volt power meters 10 and 20 watts respectively.

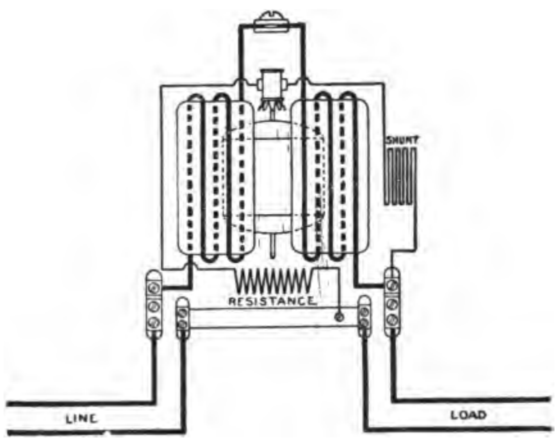


FIG. 22.

We now pass to the general consideration of the meter and the means of connecting it for registering various forms of commercial service.

Fig. 21 may be taken to represent the general interior appearance of the various forms.

In the diagrammatic representations, Figs. 22 and 23 are shown the methods of connecting all meters of the two-wire type, whether for light or power purposes, direct or

alternating current. The service feeds on the left, and the disk rotates counter-clockwise as seen from the top. The high efficiency three-wire type is connected as shown in Fig. 24, in sizes up to 150 amperes. Over this capacity the circuit is metered by two meters of the two-wire type. In the metering of polyphase systems by the Thomson meter a variety of connections are used. The characteristics of the circuit govern the method pursued.

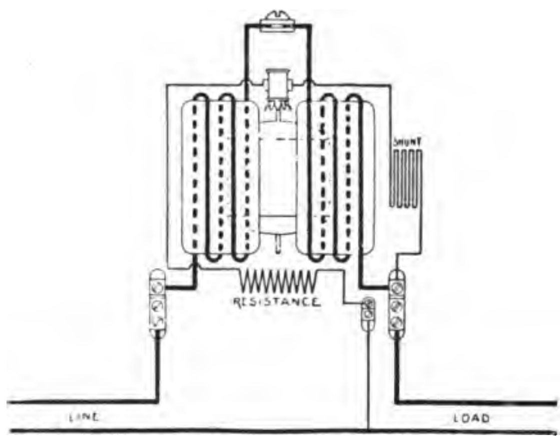


FIG. 23.

Before passing to the measurement of Alternating Polyphase currents we wish to call attention to a grave defect in the three-wire meter, Fig. 24, which may lead to the loss of revenue if the consumer be aware of the conditions. It is seen that the armature circuit is fed between the neutral and one outside leg, and if for any cause a fuse blow on this side of the system before the meter, the remaining lamps on the opposite side of the system can be burned without causing the meter to register. Nor can this defect

be remedied by connecting the armature across the two outside legs, as, then, if either fuse blow, the meter stops unless some lamps are in circuit on that side of the system. In that event the armature would receive less than one-half its voltage and the meter register less than one-half of what it should. Therefore, the removal of a fuse, or the splitting up of the main switch before the meter into single pole switches, could be used by designing and unscrupulous persons to rob the company furnishing current of a large

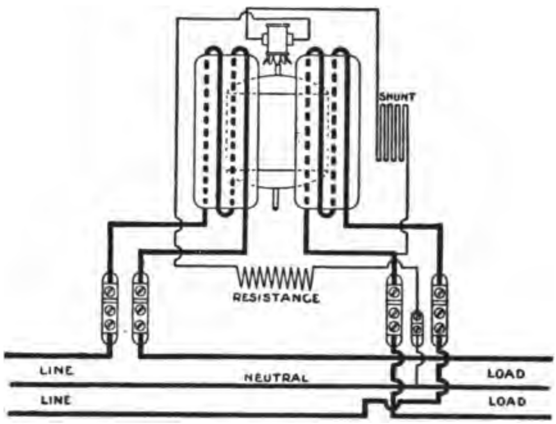


FIG. 24.

amount of revenue. No doubt the manufacturers of this meter are fully aware of this defect, but the central station is certainly taking chances when installing it of being deprived either through accident or by intent of a portion of its just revenue. There are a number of simple remedies that can be applied in the way of small auxiliary devices that will automatically cut the armature over to the live side of the circuit and preserve the proper polarity of the leads so as not to reverse the armature. Some such

provisions should be made to make this meter a safe one, as no one can take action against the consumer for removing a plug and burning half of his lights, when he in no way touches or molests the meter.

The temptation for a certain class of customers, when they understand the meter, is too great for them not to

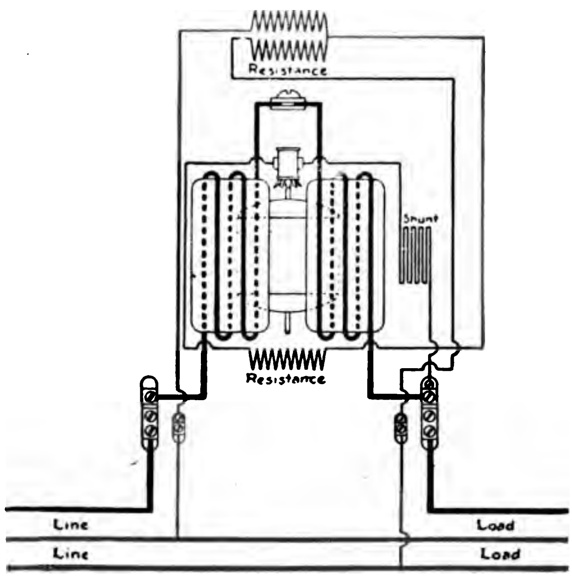


FIG. 25.

take advantage of what is obviously the fault of the company in providing such a simple and safe meter to "beat."

The theory of the measurement of polyphase systems by means of non-inductive meters has been set forth in Chapter II; hence, simply the application of the principle therein outlined will be given in the diagrams for metering the different systems.

In balanced three-phase circuits, one two-wire meter connected in either one of the three legs with the armature, fed by the energy voltage of the circuit, will register one-third of the total power passing; hence, multiplying by 3, we obtain the total energy passing in the three legs of the circuit. Such a connection is illustrated diagrammatically in Fig. 25, where the armature forms part of one of the legs

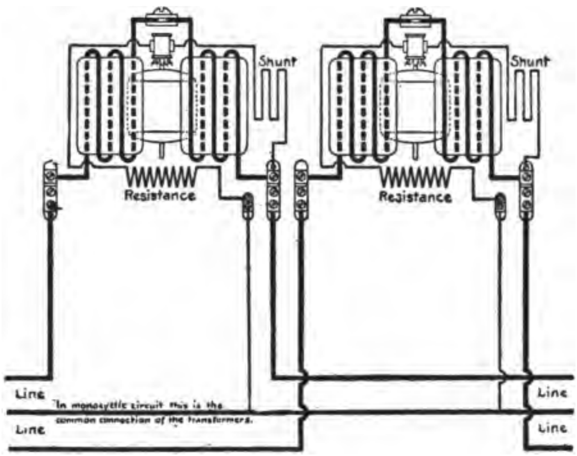


FIG. 26.

of the set of Y connected resistances. The voltage from the common center to either point of the Y is energy voltage of the system. This connection may be used for either light or power, but must always be used on a balanced circuit and one that has the same power factor for each phase.

Unbalanced three-phase circuits are metered by placing two two-wire meters in two legs of the circuit and connecting one end of the armature circuit of each meter to the

feeding leg, and the other end to the unmetered leg. This connection is illustrated in Fig. 26.

In an unbalanced three-phase system employing four wires in its distribution, the power flowing in any of its three phases is found by connecting a two-wire meter in that phase, and feeding the armature between the leg metered and the fourth wire or common neutral.

This is practically what is done in the balanced three-wire system, the difference lying in the extension of the

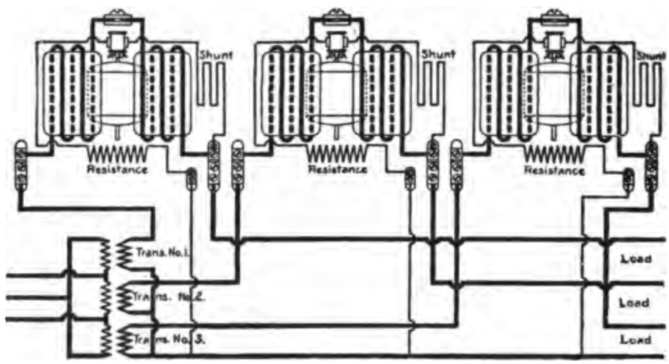


FIG. 27.

neutral point of the three phases to the distribution. To meter the total power flowing in the four-wire unbalanced three-phase system, the three phases must be metered as shown in Fig. 27, and the results of all the readings added.

In the two-phase systems employing four wires in the distribution, two meters are used if the two phases be unbalanced as indicated in Fig. 28. If the phases be exactly balanced, one meter connected in one phase is sufficient, the total energy passing being double its indication. The connection for the meter is shown in Fig. 29.

Two-phase systems employing a common return, and distributed by means of three wires, are metered in the same manner as three-phase systems.

The measurement of monocyclic circuits by means of Thomson meters has been, in many cases, erroneously consummated. In Fig. 30 one meter is shown connected into a monocyclic secondary circuit, the meter being of the three-wire type with a common armature for both fields. Such a

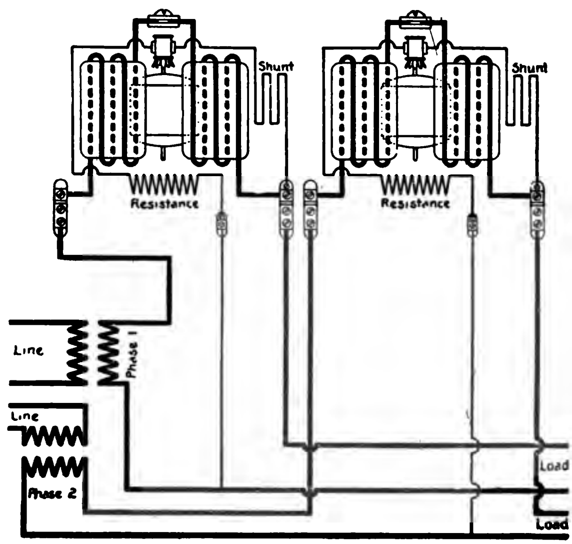


Fig. 28.

connection will not give the correct register of the energy passing in the circuit. This connection has been in use upwards of five years, but, from carefully conducted tests by the author, it has proven beyond a question that about 33⅓ per cent. of the current remains unregistered. The manufacturers have now ceased to put out this meter as

correct, and meter monocyclic current by a regular three-phase induction meter, or by means of two Thomson meters connected in the same manner as shown in Fig. 26, for unbalanced three-phase circuits. It is readily seen, where two legs of an unbalanced three-phase system are placed in relation with the potential circuit of only one of them, that a correct registration cannot be obtained. In Fig. 30, the current in the left hand field for a portion of each

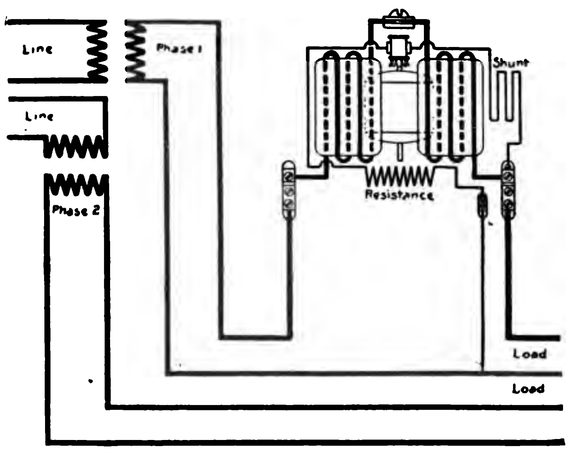


FIG. 29.

period opposes the current in the right hand field, as they differ in phase by 120 degrees. The torque exerted on the armature is the product of the algebraic sum of the two-field currents and potential circuits, instead of the arithmetical sum of the two-field currents and potential circuit. Another form of monocyclic secondary circuit is that shown in Fig. 31, wherein lights and motors are fed from the same circuit, the teaser current being measured independently of the light circuit. As is shown, two meters

are used to meter the total energy passing. Various adaptations of this meter have been made to fulfil special conditions, such as the measurements of arc circuits and storage battery circuits where the one meter measures the output as well as input of the battery.

The Thomson meter, judged in the light of the requisites of a good meter, fails in several qualifications, and has several faults peculiar to itself.

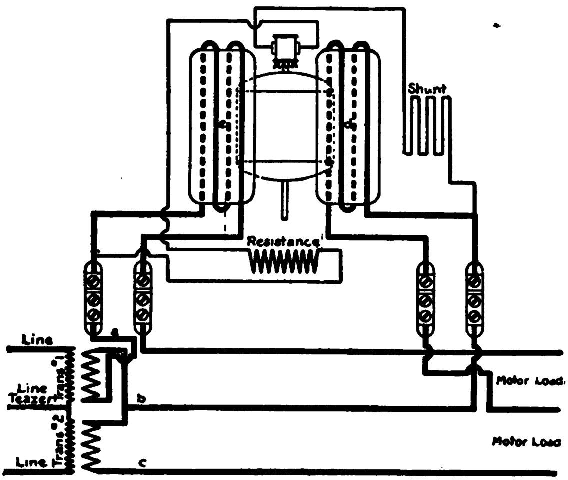


FIG. 30.

The torque of the meter is small with regard to its frictional counter torque, having a ratio of 50:1 in a new meter, but more like 20:1 after it has been in service a few months. The effects of this are slowness on light loads and consequent loss of revenue.

In the matter of friction balancing, we have seen that a coil is provided which produces a turning movement on the

armature supposedly equal to friction of the moving parts. As this friction is an ever varying and often ever increasing quantity, the friction balancing produced by the coil is unsatisfactory. When the friction is diminished, by whatever cause, the meter will "creep" on no load, and lead to complaint and distrust on the part of the consumer.

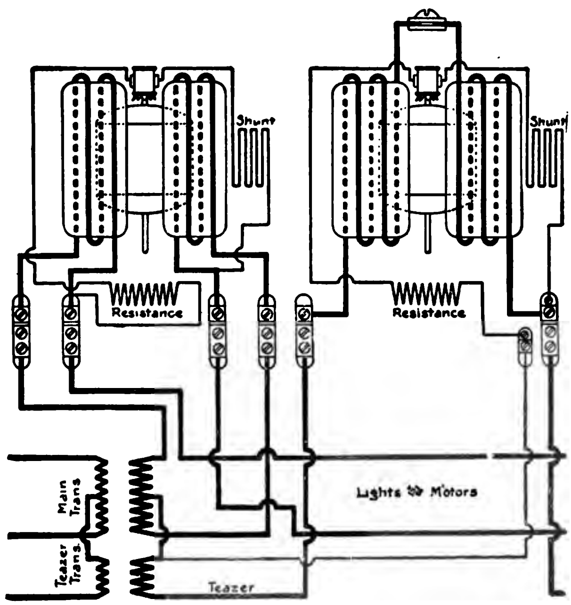


FIG. 31.

The supporting of the armature, which weighs, complete, over half a pound, on a hardened steel point resting on a highly polished jewel surface, furnishes a very small amount of friction while the jewel and shaft end retain their integrity, but causes no end of trouble the minute either of them becomes rough.

The armature is subjected to vibration, and rapidly pounds the jewel to pieces. This causes the friction of the meter to increase enormously and frequently stops it.

The tropical type of meter is supposed to be air-tight, but it is not sufficiently so to exclude acid fumes, insects and dust, and all of these exert a deleterious effect on the accuracy of the meter.

An apparently trivial defect is the flaking off of the paint used on the permanent magnets. This paint is magnetic, and will stick out like stiff bristles from the poles of the magnet and drag on the disk, retarding the meter appreciably and sometimes stopping it.

The remedy for this trouble lies in tinning or copper plating the magnets instead of painting them.

From a long series of records kept very accurately, it was found that this defect was a very serious one and led to the loss of much revenue.

Stray iron filings produce a like effect, and, in the small meters having iron set screws in the binding post, it has been found that, in setting up the screws with a screw-driver, small clippings of iron have been dropped on the disk with the above result of slowing or stopping the meter.

Where vibration is present, the commutator becomes rough from the sparkling of the brushes and creates friction which greatly interferes with the meter's accuracy. A piece of hard linen tape passed around the commutator and under the brushes will polish it nicely when pulled briskly to and fro. Only in extreme cases should crocus cloth be used, as it lodges small silver particles in between the commutator bars, tending to short circuit them unless a strong air blast is used to dislodge the silver dust.

The care and maintenance of the meter are outlined more fully in later chapters.

CHAPTER VII.

The Duncan Recording Wattmeter, for Alternating Current.

The Duncan intergrating wattmeter for alternating current is, in its present state, the work of many years of development. Attention has been paid to the mechanical requirements of a good meter with the pleasing result shown in the accompanying cut, Fig. 32, which shows the exterior appearance of the meter. Fig. 33 gives a clear idea of the interior construction, the mechanical and electrical details of which will be briefly reviewed.

Fig. 32.

The meter is essentially a rotating field alternating current single-phase motor with an inverted aluminum cup for an armature, and its fields consist of series and shunt coils placed at angles of 90 degrees.

The series field coil of annealed sheet steel laminations carries the form wound series coils on inwardly projecting pole pieces, while the shunt field is placed inside of the armature drum with its axis at right angles to the axis of the series fields. The shunt field is also wound on a laminated core which has a central hole to allow the shaft of the

revolving armature to pass through it. This rotating shaft carries the usual gear for operating the dial train, and is supported at its lower extremity on a spring seated sapphire jewel bearing. The pivoted point of the shaft is removable

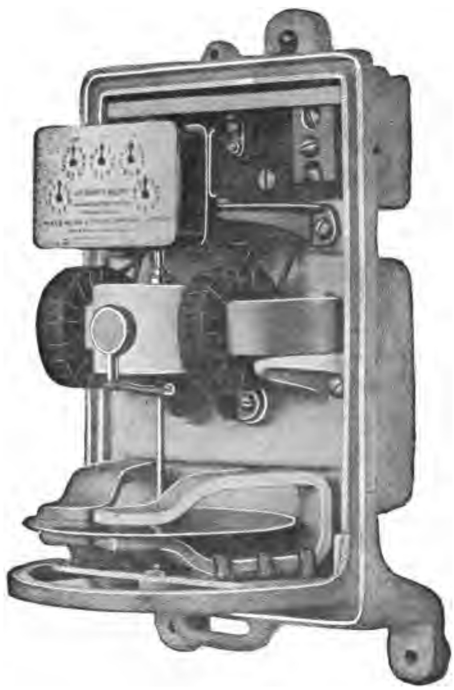


FIG. 33.

in event of its becoming injured. Just above the jewel bearing, the shaft carries the retarding disk, which revolves between the poles of two permanent magnets, and acts as a magnetic brake, the power of which is proportional to the speed.

The operation of the meter is as follows:

The current flowing in the series coils sets up a plane of magnetization at right angles to that set up in the shunt field coils, but, owing to the self-induction of the latter, and the impedance in series with it, its magnetization lags behind that of the series coil, creating a shifting or rotating magnetic field which actuates the closed secondary or armature in a well-known manner. The torque produced varies with the energy flowing. If the load on the meter be non-inductive, the magnetism of the shunt field must lag exactly 90 degrees behind the E. M. F. of the circuit.

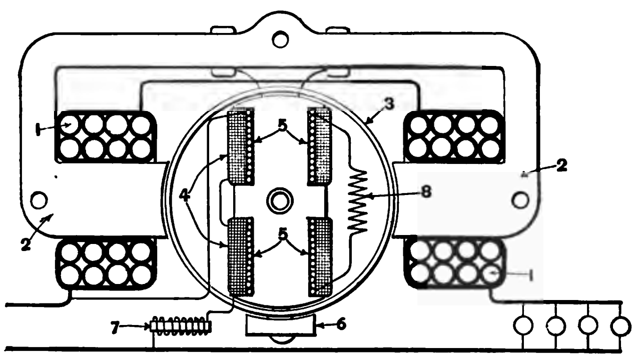


FIG. 34.

Referring to the diagrammatic view of the relation of the armature with the series and shunt coils, Fig. 34, we find at 5, a secondary coil closed through the resistance 8. As the current in the shunt field coil lags less than 90 degrees behind the E. M. F., the resistance 8 is so adjusted that the induced current flowing in the secondary 5, acting in conjunction with that flowing in the shunt field coil, forms a resultant field in quadrature with the E. M. F.

The initial friction of the moving parts is compensated for by the action of a small movable disk of iron, surrounded by a band of copper shown at 6, Fig. 34. This compensator is carried on an arm whose axis of rotation is co-incident with that of the armature shaft, and is movable concentrically to the armature over an angle of about 120 degrees. The purpose of the compensator is to give an auxiliary torque to the armature independently of the series fields, this torque being so adjusted as to just counterbalance the friction of the moving parts. When the axis of the compensator makes an angle with the axis of the shunt field coil, its magnetism is distorted owing to the iron in the compensator.

Eddy currents, set up in the armature by these lines of force cutting it, lag behind the current in the shunt field coil. The consequent magnetic pole of the inner surface of the armature, being of like polarity, repels, while the outer pole is attracted to the unlike pole set up by the eddy currents generated in the copper band of the compensator. Hence, we have a torque proportional to the angle which the axis of the compensator makes with the axis of the shunt field coil. If the compensator is moved backwards or clockwise from the axis of the shunt field, the armature receives a corresponding torque of reverse direction.

The very easy manner in which this compensator can be shifted enables the meter to be adjusted to suit a local condition; that is, if vibration be present, the meter may creep under the adjustment suitable for no vibration, but can be adjusted to just balance the friction on the customer's premises without altering the adjustment on full load.

This compensator answers the same purpose that the auxiliary coils in other meters do with the advantage, in its form, of being more readily adjusted.

The small cross section of the series pole pieces allows the coils to be of small diameter, thus cutting down the length of wire for a given number of ampere turns and reducing the I^2R losses of the fields.

The impedance coils which, in a single-phase meter of this character, have more inductance than resistance, are in series with the shunt field circuit, and serve to displace the phase between the series and shunt fields, giving the rotating magnetic field necessary for the rotating of the armature. The high inductance of these coils reduces the wattage in the shunt coil to a minimum in this particular meter down to about 2 watts. We have already pointed out the manner in which the phase of the potential circuit is made to lag exactly 90 degrees behind the current in the series fields.

The case of the meter consists of a heavy cast iron back with three supporting lugs. The cover is of sheet metal, hinging to the case by means of a slot and tongue, and fastened at the top by a screw over the head of which passes the seal wire.

The cover fits into a groove in the back lined with soft rubber, keeping out insects, dust and moisture, and is also provided with the usual window for reading the dials and auxiliary window for counting the revolutions of the armature. The wires do not enter into the main body of the meter, but are fastened into a binding block at the top of the case. In the two-wire meters, one leg only passes into the meter, the other wire of the circuit feeding the shunt field coils by a half tap. The three-wire meters have the two outside legs taken into the meter either with or without the half tap from the neutral.

The meters are designed to register accurately on inductive and non-inductive loads.

The following diagrams are explanatory of the different ways of connecting the meters for various classes of service. Other ways of connecting these meters for various kinds of service will suggest themselves from the explanations, given in Chapter II, on the measurement of power by inductive meters wherein the various connections for two and three-phase systems were given.

Fig. 35, shows a simple two-wire meter service in which only one main leg is taken into the meter, the potential circuit being fed by a half tap from the other leg.

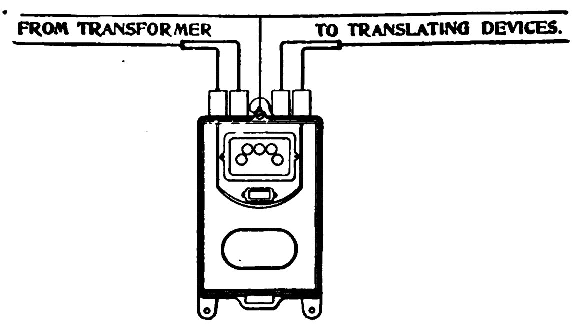


FIG. 35.

Fig. 36, is the same as Fig. 35, except for the larger lugs used for meters over 100 ampere capacity.

The three-wire system is metered by taking in the two outer legs.

Fig. 37, the potential circuit, is fed by the maximum voltage of the system. This connection is used for meters of low efficiency type; the regular high efficiency meter is connected as shown in Fig. 38.

Regular two-wire meters are used for balanced two and three-phase systems and for balanced two-phase systems

employing four wires, as shown in Figs. 39 and 40 respectively. Of course, the total amount of power consumed in

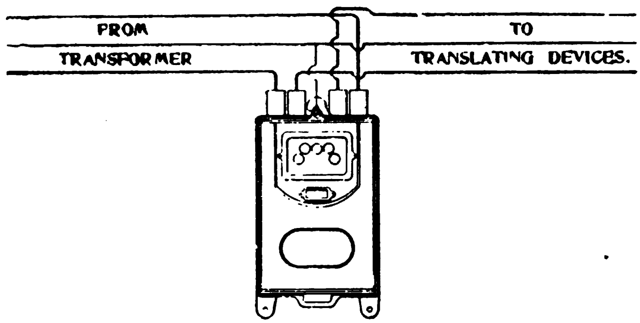


FIG. 36.

the circuit is found by multiplying the register of the meter by the number of phases.

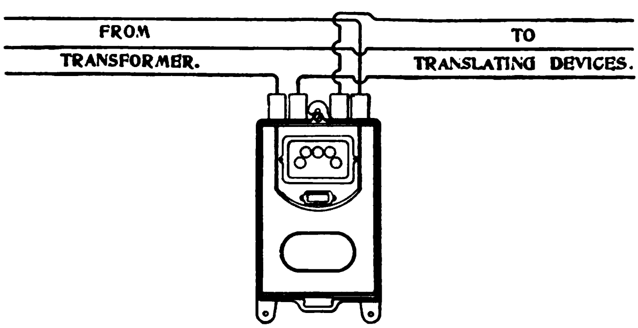


FIG. 37.

This meter may be taken as a type representative of quite a number of meters such as the Shallenberger, Shaeffer, Guttman, Packard, all of which employ similar

principles, but of course differ widely in mechanical details. All of the above, however, have a spring mounted jewel for the armature support in common.

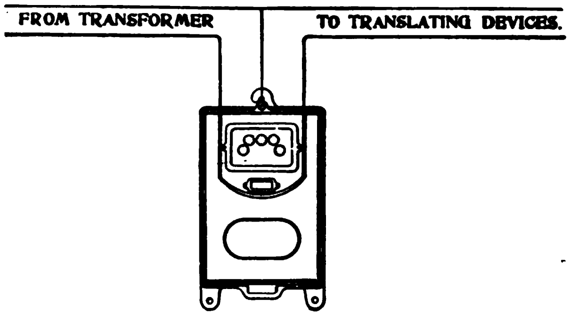


FIG. 38.

In this one point all these types of meters fail to fulfill ideal conditions, by having a variable frictional support for the

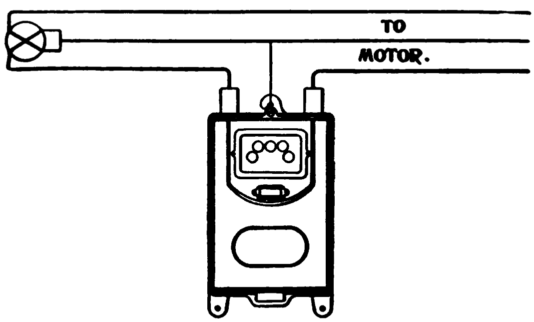


FIG. 39.

armature which changes rapidly for the worse with ill usage.

The torque in this type of meter is usually small, but the ratio between torque and frictional equivalent may be large when the meter is new, and a very accurate register of load through wide ranges may be obtained. The meter is

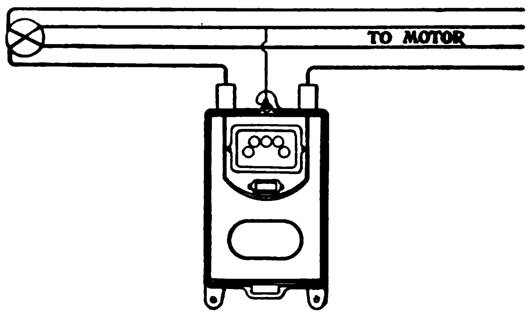


FIG. 40.

not absolutely air-tight, and is subject to all the objections which this implies.

What may be said of this meter will apply generally to all meters of this type.

CHAPTER VIII.

The Duncan Wattmeter—Commutated Type, for Direct Current.

Meters of the commutated type for use on direct and alternating current systems have been very few in number; probably the best known is the Thomson recording wattmeter.

The Duncan meter has recently been placed on the market, and its electrical and mechanical design insure for it a lasting place in the commercial meter field.

The meter is of the non-inductive type and can be used to register direct and alternating currents with equal accuracy.

Alternating current, whether inductive or non-inductive, is registered without a change in calibration; but commutated types of meters are not used for alternating current as much as inductive type meters, owing to the cheapness of the latter.

In principle the meter is a Siemens dynamometer, the stationary coils of which are energized by the current flowing in the circuit, and the movable coils or armature proportionally to the potential of the circuit in which the meter is inserted. There is no iron employed in the series or shunt fields, the armature is wound drum fashion over a non-magnetic skeleton support and provided with commutator and brushes. The field coils are placed in magnetic relation to the armature, and the whole operates as a simple motor, the current flowing energizing the fields and the potential of the circuit, the shunt field coil or

armature. The difference in operation from a shunt motor is that the shunt field circuit revolves and the series circuit remains stationary.

The details of electrical and mechanical design will prove more interesting than a repetition of the theory of opera-

FIG. 41.

tion of meters of this type contained in the Chapter VI, on Thomson wattmeter, with which we are already familiar.

Fig. 41, shows meter with case on and it is noticed that

the meter hangs from the top lug of the frame and is levelled horizontally by the side lugs. This is a very convenient feature in installing, as the workman can insert his top screw and then hang the meter on it. The capacity and voltage of the meter are marked in plain figures on the

FIG. 42.

case. The case is made air-tight and is hinged at its lower extremity to the meter frame as shown in Fig. 45. When the case is lowered the hinge holds it in the position shown, and when it is lifted a little it comes off. This is a very convenient arrangement for inspection and testing.

The frame is made of a single aluminum casting, very light and rigid, and handsome in appearance. Around the front edge of the frame is a groove lined with felt into which the cover is securely clamped, rendering the meter dust and insect proof when closed. A seal is inserted over the screw

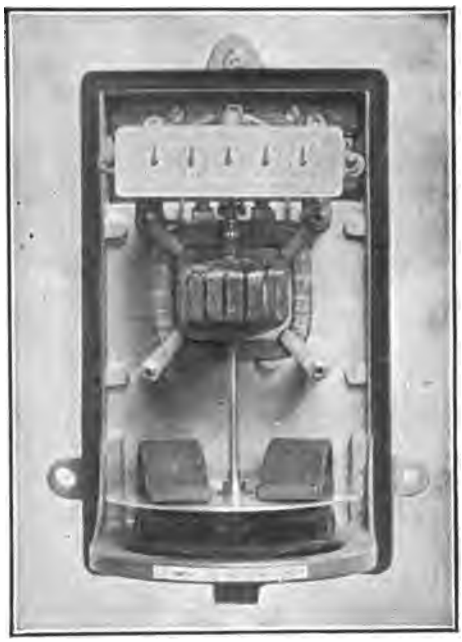


FIG. 43.

holding the cover closed, rendering access to the meter by unauthorized persons impossible, except by breaking the seal.

Fig. 42, is a front view of the interior of the meter with the case removed. In the foreground are the auxiliary,

or starting coil, and field coils, showing their relation to the armature coils. The aluminum brake disk is shown below revolving between the poles of two permanent magnets.

In Fig. 43, the starting coil and one field coil are removed,

FIG. 44.

showing the accessibility of the armature, and a still further illustration of this feature is seen in Fig. 44, where the essential elements of the meter are taken apart without disturbing the other parts. The great accessibility to all parts of the meter, and the ability to take it

apart by the removal of a few screws, are valuable features when repairs or inspection are necessary.

The perforated cage at the back of the meter encloses from mechanical injury the resistance coil in series with the armature circuit. This coil is wound of fine resistance wire, securely held in place and thoroughly insulated from the meter frame. The round hole near the top of the meter, Fig. 46, is for the entrance of the feeding wire for

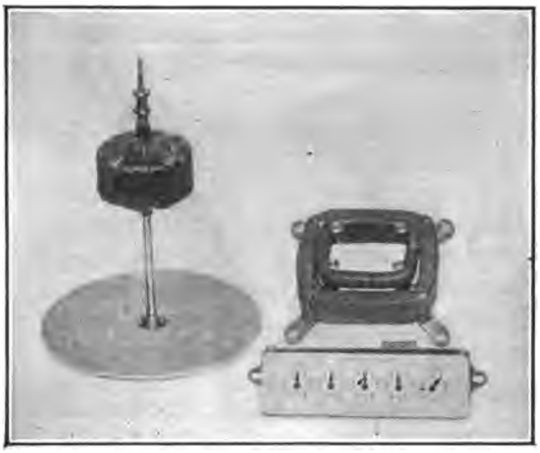


FIG. 45.

the series coils, and the half tap for the potential circuit is led in from the top. The terminals for the leading-in wires are mounted on a wooden block just inside the frame, and are inaccessible when the meter is closed.

Fig. 47 shows the case removed from the hinge, but otherwise is a repetition of Fig. 46.

Figs. 48 and 49 are views of the revolving element and brushes respectively. The worm gear at the top of the

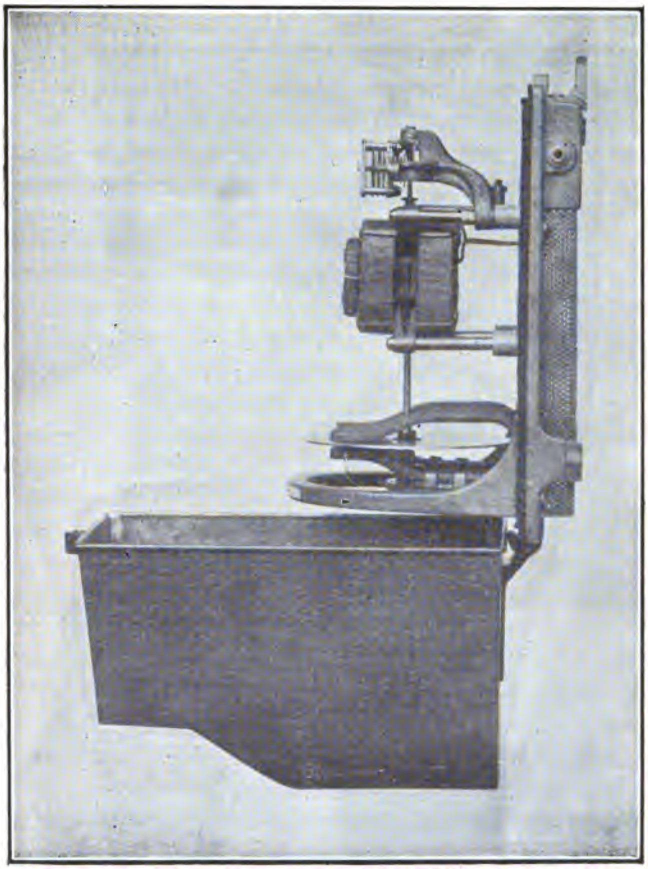


FIG. 46.

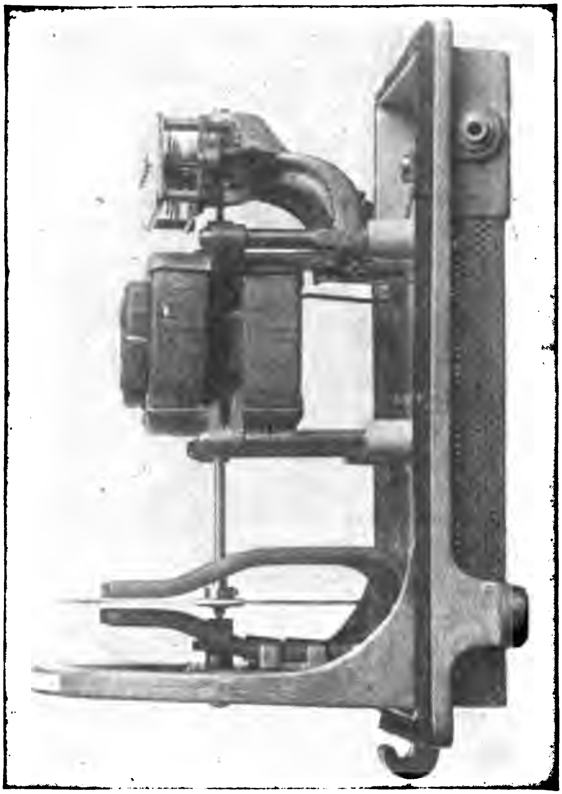


FIG. 47.

revolving element meshes into the actuating gear of the dial train in the usual manner, the relation of the gears in the dial train being so proportioned that all sizes of meters register directly in watt hours no matter what the speed of the revolving element may be. This feature eliminates errors due to the faulty recording of the multiplier by the meter reader or office clerk.

FIG. 48.

The commutator is built up of eight segments with air insulation between the bars, and is composed of a non-oxidizing metal. The brushes bearing on this commutator are tipped with the same metal.

The armature is wound with very fine silk covered wire, with a large number of turns in each section, and is

thoroughly insulated from the shaft. The aluminum brake disk is carried just above the hardened steel removable pivot which bears on the spring mounted sapphire bearing. The spring supporting this sapphire is so proportioned as to cushion the blows due to vibration by the revolving element so as to prolong the life of the jewel. The exact strength of this spring is a very important feature. The jewel bearing is contained in an ordinary filister head screw which can be easily removed for inspection or repairs.

FIG. 49.

The field coils are supported on studs mounted in the frame of the meter, and can be removed as shown in Fig. 43. The whole mechanical design of the meter is good, and is pleasing to the eye, embodying at the same time neatness and rigidity.

The dial train records in K. W. hours, and has five recording circles in a straight line. The figures are plain and

the elimination of the constant or multiplier is a good feature.

The meters are manufactured for two and three-wire circuits; diagrams of the various connections need not be given as they are the same as those shown in Chapter II, for the various classes of service.

The meter will be considered in connection with the various requisites of a good meter given in Chapter III.

First: Varying Voltage and Load.

On loads from 5 to 100 per cent. the meter has a very good accuracy curve, but, as the friction is equal to about 2 per cent. of full load torque value, any increase in friction has a deleterious action on accuracy. The mechanical design of the meter is such, however, as to reduce this loss to the lowest limit for meters of this class. The voltage is registered correctly through a wide variation, no appreciable error arising from this source.

Second: Varying Frequency.

As the meter has no iron in its magnetic circuits, the effect of varying frequency is eliminated. The meter needs no change of calibration for circuits of 7,200 or 16,000 alternations.

Third: Power Factor.

Variations of power factor are met accurately, a full description of power factor variations for non-inductive meters being given in Chapter II.

Fourth: Wave Forms.

Owing to the absence of iron in the magnetic circuits various wave forms have no effect on the accuracy of the meter.

Fifth: Short Circuit.

A short circuit on the lines could cause a rush of current which would largely increase the magnetic field surrounding the field coils and, if heavy enough, cause an alteration of the magnetic strength of the permanent magnets. There is no provision made for shielding against such an occurrence.

Sixth: Permanence of Magnetic Drag.

The manufacturers claim a very high degree of permanence for the magnets owing to a special process which is the outcome of long experience. The meter has not been in commercial use long enough to verify or disprove this statement.

Seventh: Torque.

The torque of the meter is as large as it is possible to obtain from the energy expended and the design of the meter. The torque is about fifty times as great as the counter frictional torque, and the ratio of the meter is therefore one to fifty. From Chapter IV, we find that it would not be good design to further increase the torque at the expense of further energy losses. Hence, the meter fulfills the requirements of torque for the given frictional load.

Eighth: Friction and Friction Balancing.

Every device known to the art has been used to reduce friction from the moving parts, but as all commutated meters have a brush friction which it is impossible to eliminate, besides a dial friction and a friction due to the weight of the revolving member on the lower bearing, it is not entirely frictionless. A compensating coil is provided

to overcome the initial friction of the meter, which is found to be about 2 per cent. of full load torque value. This friction compensator is not adjustable.

Ninth: Energy Losses.

The losses in the potential circuit are, for the 110 volt series, about four watts, and vary in the field circuits according to the size of the meter, averaging about 1 per cent. of the capacity of the meter at full load.

Tenth: Armature Support.

The armature is supported on a highly polished sapphire bearing, which is mounted on a spring of such tension as to produce a cushion for the armature to all jars or vibration to which the meter may be subjected. This type of bearing is the best known to-day, where end bearings are used at all. The hardened steel pivot resting on the sapphire is ground to a ball point and highly polished. The aluminum brake disk lightens the revolving element and reduces the friction due to weight.

Eleventh: Air Tight.

The construction of the cover and its seat in the felt-lined groove render the meter practically air-tight. It is proof against acid fumes, dust, insects, etc., which are all so injurious to meter accuracy.

Twelfth: Temperature Co-efficient.

The temperature co-efficient has been carefully worked out and is, for all practical purposes, unity.

Thirteenth: Insulation.

The insulation between wires and frame exceeds one megohm.

Fourteenth: Mechanical Features.

In the various figures illustrative of the meter, the mechanical features were dwelt upon. The main points are rigidity and lightness, and this meter combines both in a remarkable degree.

It is noted from the foregoing that the requisites of a good meter are fulfilled in a satisfactory manner by the Duncan commutated meter, and it is a worthy example of careful design and well-thought-out details.

CHAPTER IX.

The Stanley Recording Wattmeter.

The meters heretofore described have one essential characteristic feature in common, a jewel bearing for supporting the armature shaft. It is well known that in alternating current meters of the induction type the alternations of the current impart a vibration to the armature shaft, which in time roughens and destroys the smoothness of the supporting jewel surface, thereby introducing friction and impairing the accuracy of the record.

In the Stanley meter the lower bearing or jewel support is entirely dispensed with, the armature being magnetically floated. The flat aluminum disk armature is mounted in a soft steel core, which is sucked up, so to speak, to a position of flotation by a magnetic system composed of permanent magnets.

The shaft is aligned in a vertical position in this system by hardened steel wire passing through phosphor bronze guide rings in center of armature core.

These guide rings are very accurately placed, so that the axis of rotation corresponds as closely as possible with the axis of the magnetic system. Upon the correctness of this adjustment depend in great measure the frictionless qualities of the support.

Fig. 50 presents a view of the exterior of the meter. Fig. 51 shows the front part removed, disclosing the front compartment containing the permanent magnets, etc.

In the foreground, Fig. 51, are seen the permanent magnets with their poles in contact with pole pieces pierced

with holes, with projecting rings corresponding to like rings in the armature core. This enables the core to assume a definite position in the magnetic system. A clear understanding may be had of this magnetic relation if we liken it to that of a solenoid, the position assumed

FIG. 50.

MODEL G—METAL ENCLOSED.

by an iron core in the solenoid corresponding to the magnetic flotation of the armature shaft in the flux established by the permanent magnets.

Adjustable pole pieces are provided which, in conjunction with the armature disk revolving between

them, furnish a magnetic brake of the usual character for the meter. These pole pieces are adjusted vertically, thereby varying the reluctance of the air gap, and, the magnetic flux passing through it, resulting in a like variation of the power of the braking action.

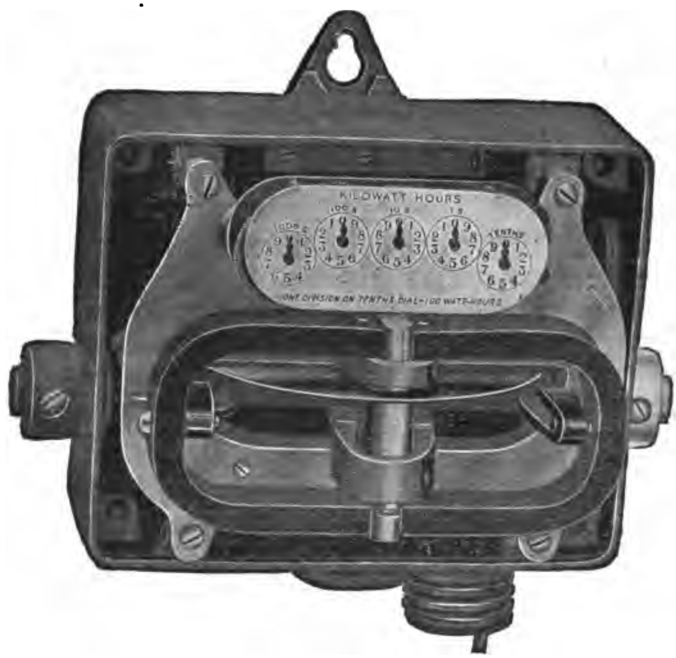


FIG. 51.

FRONT VIEW OF SUPPORTING FRAME, SHOWING BRAKE MAGNETS, DIAL, ETC.

Fig. 52 shows in more detail the magnetic suspension elements of the recent model G meter, and the method of suspension of the magnetically floated armature.

The magnetic suspension elements consist of the

permanent magnet Y, and the steel plugs or pole bushings, A and B.

The rotating parts floated in air are the aluminum disk and the soft steel vertical shaft, called suspension core, to which the disk is rigidly secured.

The lower end of the suspension core is flanged larger, while the upper end is turned smaller in diameter than the body of the core.

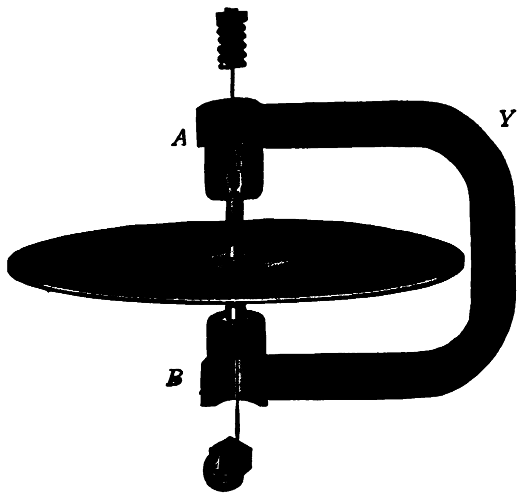


FIG. 52.

The flanged lower end of the suspension core enters a cup formed in the lower pole bushing B; its upper end, when in magnetic suspension, is just inside of a recess in the upper pole bushing A.

The difference in diameters between the flange of the suspension core and the cup in the lower pole bushing B, as also between the upper end of the suspension core and

the recess in the upper pole bushing A, is such that there is a predetermined space all around the flange in pole flushing B, and all around the upper end of the core in pole bushing A.

When the suspension magnet is not in place the flanged end of the suspension core, due to gravitation, will naturally rest on the surface of the cup in pole bushing B; but, due to difference in diameters, it will not touch the circumference of the cup at any point, there being an air space between the periphery of the flange and the circumference of cup.

When the suspension magnet is not in place, and when the lower end of suspension core rests on the surface of the cup in pole bushing B, the upper end of the core will be slightly below the lower edge of the upper pole bushing A.

Magnetism passes between the ends of the magnetized plugs (pole bushings A and B), attracts the steel suspension core, with the disk attached, in an upward direction, lifts the flanged lower end of the suspension core from contact with the surface of the cup in the lower pole bushing B, and carries the upper end of the suspension core into the recess in the upper pole bushing A.

By the laws of magnetism, the magnetic field, into which the suspension core with its attached disk is thus attracted, acts uniformly upon the suspension core, holding the rotating parts in a predetermined definite position in space, free from mechanical support or contact of any kind.

The actuating part of the meter is contained in a closed iron compartment which shields it magnetically from outside influences. A slot in the case permits the armature to revolve between the poles established by the series and shunt field coils in circuit with the energy to be

measured. The field coils are ribbon-wound and mounted one below and one above the disk. The shunt field coils, four in number, are carried on a laminated yoke, having projecting pole pieces straddling the ribbon-wound series coils.

The method of obtaining the "lag compensation" for the potential circuit differs in this meter from the usual form of impedance coil with short-circuited secondary.

The potential circuit is wound around a laminated magnetic yoke having two air gaps in its magnetic circuit. The reluctance of these air gaps is so proportioned that an initial lag angle of about eighty degrees is obtained. The introduction of the armature disk into these air gaps is so designed that the resultant eddy currents set up therein react upon the magnetic flux in such a manner as to displace the effective flux by ninety degrees from the impressed voltage of the system.

This phase-angle depends upon the conductivity of the inserted closed-circuited disk, and is the complement of the angle of lag of the energizing coil.

The revolving magnetic field set up between the potential and current fields, cutting across this closed secondary or armature, induces eddy currents therein. The reaction of these currents on the primary field produces rotation of the armature at a speed proportional to the energy passing.

The service feeds the meter on the left side, the disk appearing, when observed from above, to revolve in the same direction as the hands of a clock. The meter is sealed so as to be air-tight, and is guaranteed by the makers for a period of three years. An especially good feature about the design of this meter is the absolute exclusion of dust, insects, etc., and it is, in this respect, ahead of the meters now on the market.

The energy consumed in the potential circuit is about $2\frac{1}{2}$ watts; the I^2R losses in the fields are small, owing to the small radius of the winding and consequent short length of conductor. Great accuracy is claimed for this meter. As the meter is suitable only for alternating current, the usual methods of connecting it in circuit are the same as apply to all induction meters. The absence of a compensating device for friction shows how much the ratio of frictional equivalent to torque is reduced by this method of supporting the armature spindle. A slight oscillation is noticed in the armature disk when no load is on which is caused by the slight difference in radical conductivity of the disk in which eddy currents are generated. A zero point is soon reached and the oscillation stopped. It will prove of great interest to watch the commercial life of this meter which in so many respects is a radical departure from the ordinary types. Its history is now in its infancy, and no trustworthy conclusions can be drawn as to its life without more extended service. The meter is manufactured in the usual commercial sizes and for various frequencies. This meter promises to fill more fully the requisite of a good meter than any other type, owing to the permanence of its fractional equivalent. The effects of short circuits on the permanent magnets are entirely eliminated, as the field coils are mounted behind a steel shield which effectually keeps any magnetism from straying beyond it. The permanent magnets are long and the pole pieces are held in an absolute relation by being mounted in a brass yoke. This prevents any widening of the air gap and consequent change in meter speed. While the torque of this meter is not any larger than many others, the frictional equivalent is so exceedingly small and so constant that a very high degree of permanent accuracy is obtained

on very light loads. The supporting of the shaft by a magnetic flotation removes all vertical friction, and the horizontal friction of the guides is practically eliminated by placing the armature core in the exact center of magnetic stress, so that the pull in every side is balanced. The friction of the dial train is probably greater than the other friction, but is inappreciable; hence, it is unnecessary to have a frictional balance.

The absolute permanence of the armature support renders the meter impervious to vibration, and as it is hermetically sealed, all acid fumes, dust, etc., are excluded, and the elements of the meter retain their same relation towards each other for a long period of time.

CHAPTER X.

The Guttman Wattmeter.

Induction wattmeters of different makes have their main characteristics in common, viz., a series field in quadrature with a potential circuit and some form of friction compensator.

The Guttman wattmeter in its present form possesses

FIG. 53.

considerable merit, and has a very pleasing mechanical appearance. Fig. 53 shows the meter with case on, and Fig. 54 with case removed.

A better idea of the rotating mechanism of the meter is obtained in Fig. 55, wherein the cover, dial and permanent magnet are removed.

Like the Stanley meter, the armature and retarding disk are combined in one to form the rotating armature.

In the old style Guttman meter, the armature took the form of a long spirally slotted cylinder, and a separate disk was acted upon by a permanent magnet to furnish the brake.

FIG. 54.

The same principle of operation is used in the new meter as in the old, except that the spirally slotted cylinder and disk are combined in one. The torque of the meter is obtained by the interaction of the slotted armature disk with the magnetic fluxes set up by a laminated shunt magnet and a small set of series fields. The armature is carried on a short shaft having a ball shaped pivot to fit

the supporting jewel, and is geared by means of a worm at its upper end to the usual dial train. The whole armature weighs only about five-eighths of an ounce, so that the wear on the jewel bearing is very slight. The shunt and series

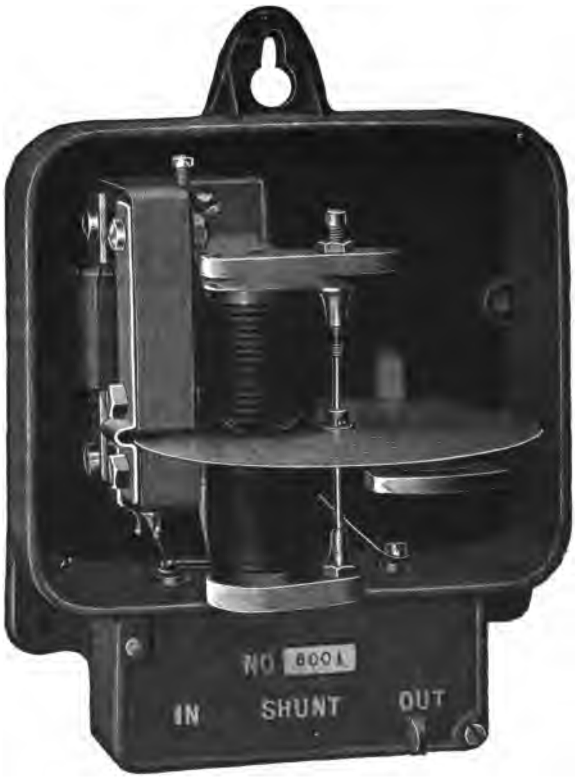


FIG. 55.

magnetic circuits are composed of two parts; a laminated steel magnet body carrying the shunt field coil, and the "bridge" carrying the series coils.

On the inner side of the shunt field magnet is held the compensating device, which is adjustable by means of a screw. A good view of the shunt and series magnetic fields is obtained in Fig. 56, which shows their mechanical

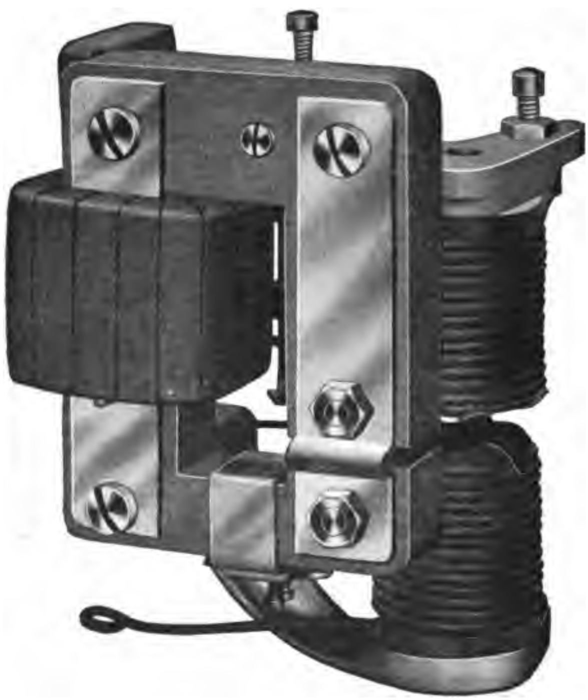


FIG. 56.

relation to each other plainer than any amount of description could.

In the series field magnetic circuit we have two air gaps which add slightly to the reluctance of the entire magnetic

circuit, but this addition is so slight as to scarcely affect the self-induction of the shunt field coil.

The compensation of the meter for inductive loads is effected by means of a heavy copper band with a small gap in it, attached to the bridge on the lower side. This gap is closed by means of a resistance wire of such size as to permit enough induced current to flow to effect the desired compensating effect.

The secondary current induced in the band, when of the correct amount, reacts upon the field just enough to cause it to be in apparent quadrature with the impressed electromotive force. The secondary induced currents in the armature will then be of the right phase to measure the true energy passing in the circuit when acted upon by the flux from the series coils. For low frequencies the resistance of this connection across the gap in the band is decreased, and it is made adjustable for different frequencies.

The series coils are held by means of aluminum clamps, and are placed in such position as to obtain the maximum rotating effect on the disk.

Each coil is 1.4 inches long and 1.25 inches in diameter; being small, they have very little resistance or self-inductance.

The permanent magnet for the retarding effect is, in the main, of the usual form, but differs slightly in its shape from either the Thomson or Duncan.

The meters are sent out sealed from the factory, and the connections are made to the service wires without getting into the interior of the meter.

The meters are made in two and three-wire, and are connected in circuit in the same manner that any induction meter would be.

For all meters above fifty amperes a series transformer is used, and a potential transformer is employed where more than 250 volts are required.

The mechanical features of the meter are excellent; it is light, compact, well made, and is dust and insect proof. There has hardly been time as yet to determine its durability. The dial reads directly in watt hours, and the ratios of the armature shaft and dial train are changed to suit the different speeds in large and small meters.

The meter has a good temperature co-efficient and low watt losses in the shunt and field circuits. The loss in the potential circuit varies with the voltage and frequency, but ranges from ½ to 1½ watts. The field losses average two watts at full load. Owing to the lightness of the armature, the frictional torque is low, and accuracy is claimed on two per cent. of the rated capacity.

CHAPTER XI.

The Westinghouse Induction Meter.

Probably one of the earliest forms of induction meter used for commercial purposes was the Shallenberger ampere-hour meter. This meter has become obsolete in modern practice, although it may still be found connected in a number of instances.

The Westinghouse company, during the past few years, has been manufacturing a meter that registers watt-hours instead of ampere-hours. It is made single and multi-phase in all standard frequencies.

Fig. 57 shows the exterior of a single-phase meter, and gives a good idea of the neatness and compactness of its mechanical features.

In theory the meter is similar to all induction meters in that the field maintained by the potential circuit is in quadrature to the series field when registering non-inductive loads.

The laminated sheet steel yoke carrying the shunt and series windings is clearly shown in Fig. 58. It will be noticed that the shunt coils are two in number, and are carried on the half of the yoke from which projects two annular shaped pole pieces. The series field consists of a few turns of wire wound round an upwardly projecting pole piece.

In series with the potential winding is an impedance coil which approximately places the shunt field coil in quadrature with the series field. A short-circuited secondary winding wound over the potential coils is

adjusted through the resistance coil shown in Fig. 58, in such a manner as to place the fields in exact quadrature.

In this secondary winding is placed a resistance bar on which slides the connector A, Fig. 58, which moves to right

FIG. 57.

or left to furnish a balancing friction compensator. Before adjusting the meter to run under load, an adjustment for frictional load should be made. Move the connector A, Fig. 58, to the right until the meter runs with a positive movement without any load. The steadiness of this

movement of the meter disk will determine whether any stickiness or intermittent friction exists. When this is determined the sliding contact should be moved to the left until the meter stops.

The meter may then be adjusted on full load, and for all loads down to about 2 per cent. of the full load. Coils may be cut in or added to the closed secondary surrounding the shunt field coils in order to secure the proper position of the sliding contact *A*, Fig. 58, near the

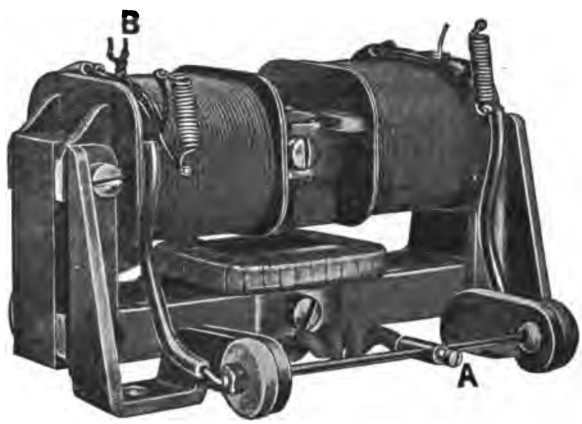


FIG. 58.

middle of the resistance bar on which it slides. The closed secondary coils are wound in such a manner as to allow of their being easily connected to make the meter correct on frequencies varying over a wide range as from 7,200 to 16,000.

The revolving element consists of a short shaft on which is mounted an aluminum disk of small diameter, this aluminum disk revolves between the poles projecting internally from the magnetic yoke. The magnetization set

up by the current flowing in the shunt and series fields acts upon the aluminum disk, creating therein induced currents which react on the rotating field in a manner to revolve the disk with a torque varying according to the energy flowing.

When the load on the meter is non-inductive, the current in the shunt field lags 90 degrees behind the E.M.F. of the circuit. As the power factor decreases, the shunt field becomes more in phase with the E.M.F. of the circuit. Hence, the meter registers accurately inductive or non-inductive loads.

The latest form of meter has a ball bearing support. The end of the armature shaft contains a cup-shaped jewel which rests on a small, highly polished steel ball, which is, in turn, supported in a cup-shaped jewel bearing. The steel ball constantly turns as the meter revolves, and furnishes an excellent support. In fact, so accurate are these meters that a straight line accuracy curve is obtained from 2 per cent. to 100 per cent. load, a slight falling off is observed after full load, and on 50 per cent. overload the meter is from ½ to 1 per cent. slow.

The three-wire meters are provided with two field coils wound over the projecting pole piece, one in series with each outside leg of the three-wire system. Otherwise, the meters are identical with the two-wire type. The shunt field coil is connected between the neutral and an outside leg. Polyphase meters have two distinct single phase units, placed one above the other, and acting on a single armature having two disks. These two single phase units are connected up exactly as though they were separate meters under separate covers. The meter case is necessarily longer than the single phase units, but otherwise the meters are the same in their make-up.

The regulating device consists of the usual permanent magnet, which acts as a brake on the disk which revolves between its poles. The meter is made fast or slow by moving it in or out. These magnets are given a special treatment which ensures their remaining permanent for a number of years. The dial face is provided with five dials which read from right to left. A complete revolution of the first right hand dial indicates one kilowatt hour, and the succeeding dials increase in multiples of ten. No multiplier is used, and the meters read directly in kilowatt hours. The meters are connected for various circuits as outlined in Chapter III. The current consumed in the potential circuit varies from 1½ watts to 2 watts, and the loss in the fields at full load is negligible owing to the small number of turns and the small radius of the coils.

The torque of the meter is small, but large in proportion to the weight of the revolving element which is unusually light. The ratio between torque and friction of the meter is large, hence the great degree of accuracy obtained over a wide range of loads and on extremely light loads.

The meter box is sealed so that it is air-tight and dust and insect proof. The inleading wires do not enter the body, but are designed to connect under binding posts contained at the top of the meter.

The cast iron body containing the meter forms a thorough shield from outside magnetic influences. The presence of strong external magnetic fields, has no influence on the accurate registration of the meter.

It will be of interest to watch the life of the ball bearing armature support; it has every indication of being a vast improvement over the pointed steel shaft both in point of life and of lower frictional value.

CHAPTER XII.

General Management of the Meter Department—Records—Testing—General Policy.

The general operation of a meter department divides itself primarily into two distinct branches; the keeping of records, and the technical branch which includes testing, repairs, etc. In large central stations the meter department employs a large number of men, who are organized with a clerical and technical force. In some stations the record part is kept distinct from the technical part, the records being a branch of the auditing department. It is general practice, however, for the meter department to keep all its own records and be responsible as a department for everything which eminates from it. There is necessarily a close bond between this department and the auditing department, and the place where the work of the one is turned over to the other varies in different central stations. The keeping of any kind of records has been worked out along several well defined lines, the alphabetical system being most generally adopted, as furnishing the most convenient natural divisions. The treachery of the memory is proverbial, and it is well to trust nothing of the least moment to verbal communication; hence, the keeping of records not only involves the keeping of ledger accounts, but all of the minute details of the business. If the business be small, it is possible to carry it on with less "red tape" than would otherwise be necessary, but as the number of details

increase, it is essential to have some well defined system along which to work out and record them. Each central station has its own peculiar forms and systems; therefore, what is here written must be considered as illustrative of simply one system which has been found to fulfill the demands of the service.

Let us assume that the central station business is divided into three main departments, the engineering, contracting and auditing. The meter department lies under the head of the engineering department, but is in close touch with the other two. The contracting department, we will assume, has charge of soliciting new business, rating, etc., and is a department which represents the company's policy and interests to its customers.

All communications touching new installations, cut-offs, extensions of service, etc., are received from the contracting department to be acted upon by the engineering department. It is good practice to have all such orders go to a special clerk (or clerks) in the engineering department who disposes of them according to their character. Orders issued to the meter department, when fulfilled, are returned O. K. to the clerk, and checked up against the original order from the contracting department. Any discrepancy is at once noted and the proper steps taken to remedy the error, or orders may be issued directly to the meter department from the contracting department. In either event the order is re-issued as a record in that department. After an order for an installation has been received, there are various orders for lamps, meters, etc., to be issued by the meter department to the stock-keeper. All of these minor orders are returned O. K. when fulfilled, and a record is kept for reference.

To avoid the issuance of a great number of lamp orders during the day, each installation man is issued an amount of lamp stock sufficient for one day's needs. On his daily report the name, address and number of lamp used for installation are recorded, and the total must balance with the number of lamps returned in the original order. This system has been found to be exceedingly satisfactory and labor saving, and any shortages are easily checked at the end of the day. The meter orders are returned by the installation man, the number, size, etc., of the meter being checked and O. K'd by the store-keeper on the issuance of the meter from his stock. In this way a double check is placed on the order and the assurance of obtaining the meter ordered. The daily report, therefore, of the installation man is a check and record of the fulfillment of his orders for that day. It is general practice to keep account of the meter as an individual meter on the card system, the card telling when the meter was received, when first installed, and its general history thereafter. This may prove interesting to one who is collecting data on repair and maintenance of meters, but otherwise is not essential. The meter should be treated as an arc lamp, or any other piece of apparatus. Any peculiarity in running is readily traceable to some source. There should be no such thing as an erratic meter; one that retains peculiar characteristics which would form interesting history.

If a new meter is sent into service, and, after being installed several months, has to be brought in for repairs, the fields, armature, or any part of it, may be changed and the meter thus loses its original individuality. When retested and sent out it should conform to the known efficiency curve obtainable from the type of meter. If it does not give this efficiency curve, the trouble which exists

somewhere must be found and remedied. The life of the meter can be prolonged indefinitely by the renewal of parts. In five years it is possible for only the frame to be in the same condition as when first installed. There should be no such thing as the history of a "cranky" meter, as that expression merely means insufficient knowledge or care in locating its troubles.

An indexed list of tested stock, giving the sizes, numbers, voltage, etc., of the meters ready for insulation is all that is necessary, the meter when ordered out being scratched off the list. The record of the meter after it is installed is preserved on the meter slip as well as in the order book. The meter number is not only a guide to the meter reader and bill clerk, but also enables the consumer to check from his bill against the meter number in his premises. From the foregoing it is clear that the keeping of an individual record of each meter as a meter is superfluous and involves labor which can easily be avoided. The systematic reading and recording of the registers of the consumers is carried on by means of meter slips, giving the name, address, meter number, size, etc., of each meter on the system. The sample meter slip, Fig. 59, is one which was in use several years in a large central station, and was found satisfactory. If the reader's slip be the only record of the reading, some form of ledger is usually kept to preserve the reading in case of accident to the slip. It is much more convenient, however, to run a duplicate set of slips which will be exact copies of the reader slip. The advantages of such a duplicate record are many. There is always in the office a duplicate set of the readings of a customer for reference, the slips serve to replace each other in the event of either being lost or misplaced, and further, the slips are more flexible than the ledger. It is a recognized

practice in large stations to read approximately the same number of meters each day and have them listed according to their situation so as to avoid as much walking as

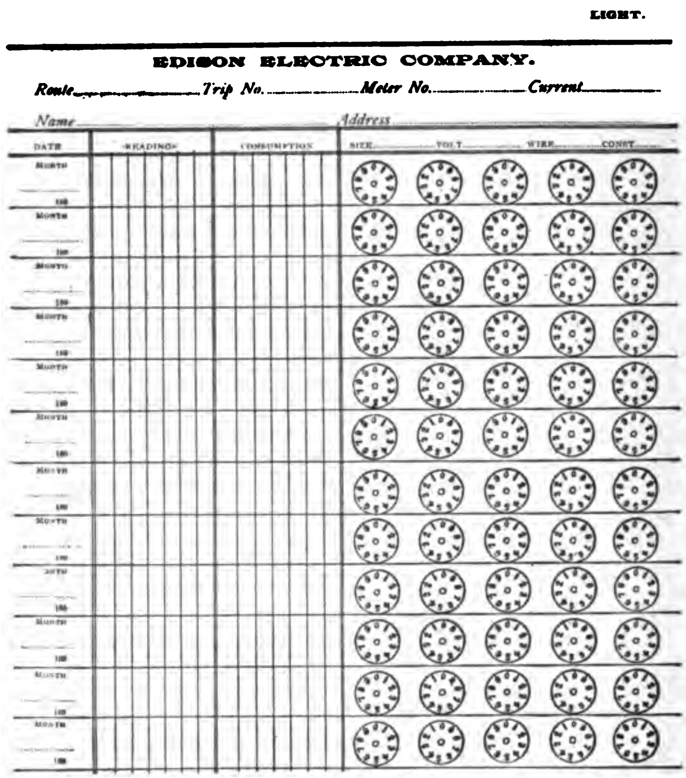


FIG. 59.

possible. These meters are indexed and arranged alphabetically while they are in their cases, and also numbered according to location, so the reader has no difficulty in

making up his route. Any new customer in the route is given the decimal part of a number in between; for example, 36.1 would be the number given a customer coming between 36 and 37 in a given route and 36.2 an additional customer between 36 and 37. After the route is read the readings are copied in the office on the duplicate slips and rendered from them into a ledger file which serves as a journal, from which to post the net bills into the consumer's ledger. The renderings in this file are checked from the reader's slips, so that any errors in copying the readings to the duplicate slips and errors in rendering are checked at the same operation. This system has been found to give eminent satisfaction, and furnishes a check on each stage of the work without checking each individual operation. The sample ledger file sheet, Fig. 60, is shown, from which a clearer idea can be obtained of the manner of rendering the bill. The dividing line between this clerical work of auditing and meter departments is usually drawn at the K. W. column on the rendering sheet, the making out of the bills, posting, etc., being done in the auditing department. Of course, this is a mere arbitrary practice and is not followed in many stations. Each bill should receive the scrutiny and judgment of the head of the meter department, or his assistant. Any abnormal increase or decrease in a customer's bill should be investigated and the reason for the same found out if possible, so as to avoid clerical errors. The meters in circuit should be tested periodically and a record kept of the test, the card system being the usual form of record. Various forms of cards are used, but the one shown in Fig. 61 is both useful and convenient. Besides keeping the record of the test for reference, it is interesting and instructive to record in a day-book the gross amount saved by these

Meter No.	NAMES AND ADDRESS		DATES	READINGS	Consumption	Cons.	K. W. Hours	Gross Bill	Discount	Net Bill	REMARKS
		Pres.									
		Prev.									
		Pres.									
		Prev.									
		Pres.									
		Prev.									
		Pres.									
		Prev.									
		Pr									
		Pres.									
		Prev.									
		Pres.									
		Prev.									
		Pres.									
		Prev.									
TOTAL,											

EDISON ELECTRIC CO., STATION NO. 1, CURRENT..................

METER READINGS, LIGHT.

Folio________

Approved________

Sheet No.________

FIG. 60.

tests. Simply the customer's name is written, and in separate columns the average per cent. fast or slow of his meter with what this means in dollars and cents taken on the basis of his last bill is noted.

At the end of each month the amount saved by these tests for one month is found by subtracting columns fast from slow. A record of this sort demonstrates clearly the saving that is effected by testing the meters, and from it an idea is obtained of how often it pays to test the meters in a

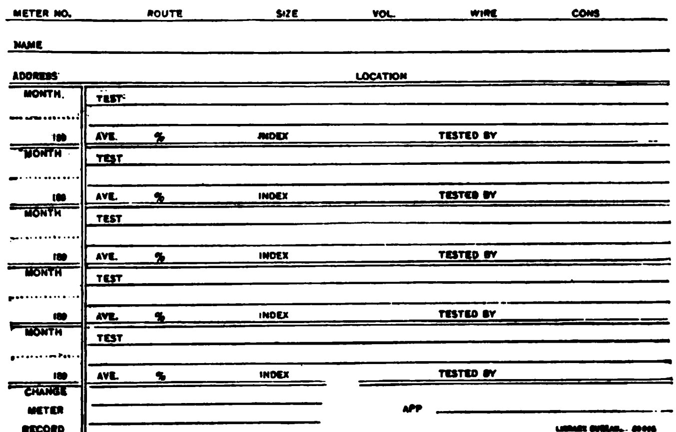


FIG. 61.

consumer's premises. Further discussion will be found under head of "Testing."

The filing of old slips and cut-offs must be done in such a way as to be readily accessible when needed. The alphabetical system furnishes its own index and is the best to follow. Any form of suitable filing case will do, and it is the practice in many stations to file all documents pertaining to a customer in one envelope, in this way reducing the en-

tire filing system to one cabinet. Under no circumstances should such records be destroyed. They become invaluable in the event of a law suit. There are many minor records, little details which vary with local conditions, but the value of keeping in writing, easily accessible, every communication pertaining in any manner to the work cannot be too fully emphasized. We pass now to the more important part of the work, where we encounter the various problems connected with the correct commercial metering of the station's output.

This part of the work is the golden key which controls the earning power of the plant. It may be divided into four branches: Repairs, Testing in the meter department, Testing in the consumer's premises, General Policy.

The repair department should be so thoroughly fitted up as to render unnecessary the sending back of the meter to the manufacturer for repairs. A thoroughly competent electrical mechanic must be secured who is capable of making all repairs of every character. Besides the complement of small tools used, the workshop needs one small drill press, one grinder and buffer, one lathe headstock. The electrical instruments needed are voltmeters according to the variety and kind of service used; a portable testing set such as the "Queen Acme."*

Meter repairs are distinct enough in character for us to retain the division between the inductive and non-inductive types. The repair of induction meters, having a closed metallic secondary for an armature, is simple. Beginning with the armature and its shaft, generally the only repairs needed will be a new shaft end, if the shaft end be

*See Kempster B. Miller's "American Telephone Practice" for full description.

removable. Except in case of mechanical violence metallic armatures should never need renewing. The potential windings of an induction meter are liable to burn out as are also the usual impedance coils or coil in series therewith. These coils are usually form wound, and can be obtained from the manufacturers at possibly lower cost than they can be wound in the repair shop. Charts of the proper impedance of the different sections of the potentional windings can be obtained from the manufacturer. The known resistances of the different parts of the potential circuit are more serviceable than their impedances, as then the wheatstone bridge can be used to verify this integrity from shunt or open circuit. When the resistance is known, a good method is to connect up in series with the coil to be tested a known resistance. A direct current passed through this circuit should give falls of potential across each coil relative to the resistance of the coils, and deviation from the determined fall of potential would indicate a fault. For example, we wish to test an impedance coil which is supposed to have 400 ohms resistance in series with this coil. We place a known resistance of 600 ohms and connect up to a 100 v. direct current circuit. If the 400 ohm coil be all right the fall of potential across it, measured by a volt meter, is 40 volts; if partially or wholly short-circuited some value under 40.

In replacing defective impedance coils, the resistance is relatively of least importance. The exact number of turns of the replaced coil must be present in the new one.

The series field coils of a meter are frequently burnt out from a heavy overload. These coils can be wound in the repair shop or bought from the manufacturer. As a general rule it is found preferable to buy all spare parts from the manufacturer and simply assemble them in the repair

shop. The greater facilities possessed by the manufacturer for turning out the various parts enable him to sell at a profit for a lower price than it costs to make them specially.

It frequently happens that the magnetic drag on alternating current meters loses some of its magnetism. This is due, no doubt, to the almost imperceptible vibration of the meter from the alternations of the current. New magnets of the requisite strength should replace magnets that have lost magnetism, as they are unreliable.

The three main matters which fill almost the entire field of repairs on induction meters are the jewel and shaft end, potential circuit and field coils.

Let us follow a meter through its different stages in the repair shop. It has been brought in from the circuit for repairs. Before examining, its reading, number, size, etc., are taken and recorded in a day book which serves as a running record of the daily receipt of meters by the repair shop. The cover of the meter is removed, thoroughly cleaned and repainted. The meter is then connected in circuit and a load put on it to see whether it is electrically or mechanically imperfect. A rough test of this character demonstrates whether the potential circuit is intact, and a glance at the field coils will tell whether they need renewing. If these parts be all right and the meter still slow, the jewel is examined, and, if cracked or broken, the shaft end as well as the jewel is renewed. If the meter has no jewel or shaft end, the friction must be looked for in the guide journal of the armature shaft. After the rough test, the meter is taken apart and cleaned thoroughly, particular attention being paid to the moving parts. After re-assembling, it is tested roughly for accuracy and grounded frame. It is then ready for the final test

in the calibrating room, the features of which will be gone into later. This general plan is followed with each meter, no matter whether cut off for repairs or simply disconnected from service. The mechanical defects in the running of a meter are easily traced. They necessarily lie in either or both bearings of the armature shaft, in the dial train or the clearance either of the armature or the retarding disk. The remedy in any case is easily applied, and presents no difficulty. Taken for granted that the meter is theoretically designed properly, the electrical defects have mainly to do with the continuity or insulation of the different circuits. If both be intact, no repairs are necessary in this quarter.

In considering the repairs of non-inductive meters, we will confine ourselves to the motor type and take as an example the Thomson wattmeter.

The repairs to this meter are varied in character owing to its having an armature composed of wire wound in coils and a commutator and brushes. The same general course, however, is pursued that has already been outlined. Mechanical defects which may influence the accuracy of the meter are the same as in the induction meter, and need not be further enumerated.

After the meter is connected in circuit, if it runs at all, a voltmeter is connected across the terminals of the brush holders, and the fall of potential across the armature coils obtained. This fall of potential varies with different types of meters, but should remain constant through one revolution or armature. If this fall of potential vary more than two volts in the different sections, it indicates a defect in the armature, and if as high as five volts, the meter can—on light loads—be seen to slow up when the defective section is reached. Armatures which are found

defective must be replaced by new ones, as it does not pay to find the defective section and re-wind it. To replace the armature the leads are unsoldered from the commutator, the set-screws holding the armature body to the shaft loosened, and the old armature slipped off. The new armature is put on, its leads soldered and the commutator given a lead of about 90 degrees from armature coils. Before placing the new armature in the meter it is well to test it in an improvised circuit, corresponding to the potential circuit of the meter. A set of brushes is so arranged that the commutator is revolved under them in the same manner as in the meter. A voltmeter connected as before indicates whether the new armature is all right. The question of re-winding armatures in the repair shop is worth considering where a large number of Thomson meters are used, and the armature renewals heavy. A regular armature winding machine, such as is used in the factory, can be purchased, or one may be improvised to answer the purpose. The winding is simple, the sections following each other in regular rotation and the loops brought out for each coil. It is nice, delicate work and can be done advantageously by girls. As many as eight to ten armatures can be turned out by one girl in a day, so that the cost of labor is very small. In small departments it would not pay to go into this kind of work, and it would be found cheaper to throw the old armature away without re-winding it. The commutator, if scarred or very dirty, should be polished with a fine piece of crocus cloth and then blown out with a strong blast from a bellows to remove all silver particles that may have lodged between the commutator bars. An extra polish is put on by finishing with a piece of legal tape, and in almost all cases a piece of legal tape is all that is needed. The brushes are

cleaned by removing the brush holder and resting the brush against a firm surface and then polishing with a piece of crocus cloth pasted on a stick. After the brush-holder is replaced, if the commutator have a tendency to spark, hold the brushes tightly against the commutator with two fingers and revolve the shaft with the other hand, the result is the freeing of both commutator and brushes of any roughness or foreign particles. The brush tension of the meter is of much importance. It should be strong enough to hold the brush on sufficiently hard to make good contact and not to fly off under slight vibration, causing arcing. Anything which causes arcing at the brushes is disastrous to the accuracy of the meter. If the tension is made too strong it is difficult to make the meter run correctly on light loads without increasing the starting coil. There is found by experiment just the right tension for the best results and the tension is ascertained by the "feel" of the brush when drawn away from the commutator. The resistance of the coil at the back of the meter in series with the armature is usually marked on it, and if this coil is burnt out it is replaced with one of the same number of ohms. The starting coil may be also burnt out and both starting coil and resistance may be wound to advantage in the repair shop. In rewinding the starting coils the same number of turns must be put on. When the integrity of the potential circuit is established in every part, the jewel and shaft end being in perfect condition, and the copper disk and armature having the proper clearance, the meter should be approximately correct. After the test in the repair room, it is turned over to the testing room for calibration. In changing a meter from a low efficiency to the high efficiency type, the alteration is confined to the potential circuit. In fact, the entire potential

circuit is changed, a new armature, resistance and starting coil being put in. The fields, frame and magnetic drag remain the same.

The change results in an increased efficiency of the meter on light loads with a decreased consumption of energy in the potential circuit. The advantages of this change make it highly desirable and all the low efficiency meters can be gradually changed to high efficiency without prohibitive cost. In changing over meters from 50 volts to 100 volts, two courses are open, the one to wind an increased resistance until the ampere flow in the potential circuit is the equivalent of what it was at 50 volts. This makes a meter of low efficiency with double the capacity of lights at 100 volts. The other course is to change the armature resistance and starting coil to similar high efficiency 100 volt parts. In either case the capacity of the meter is double that of 50 volts, and at the same constant as the regular type 100 voltmeter of the same size. An exception, however, is the ten ampere 50 voltmeter, which also has its magnetic drag halved to bring it to constant one-half. The same general policy is pursued in changing to any voltage. Meters are tested to ascertain whether they will register a given load for a given time accurately. In other words, the energy passing through the meter must make the meter revolve in exact proportion to its amounts. Nearly all mechanical meters make one revolution of the armature for one watt hour, hence we derive the formula:

$$\frac{\text{No. revolutions} \times \text{constant} \times 3600}{\text{watts}} = \text{seconds in which}$$

the meter should make the given number of revolutions. To count the number of revolutions in a given time accurately a stop watch is used. A mark is made on the

revolving disk, and a meter under test is given a run of say 20 revolutions. The exact elapsed time is caught by the stop watch, and the rate at which energy was flowing through the meter is obtained from the instruments in circuit. The application of the above formula will determine whether the meter is fast or slow.

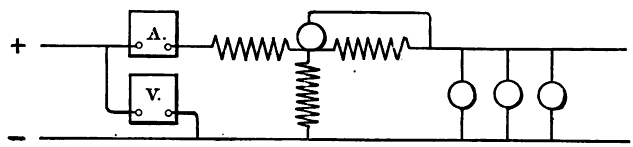


FIG. 62.

The indicating instruments to determine the amount of energy passing in the circuit are connected in a number of ways. In Fig. 62 the ammeter and voltmeter are connected before the meter, hence the amount of current used by the potential circuit is registered on the ammeter and fall of potential across the fields of the meter by the voltmeter.

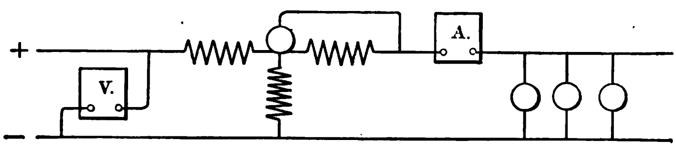


FIG. 63.

If the meter is calibrated on this basis, the consumer pays for the current used in the potential circuit of the meter as well as the loss in the fields. The usual combined losses in the meter are about 2 per cent. of full load rating, hence in this connection the consumer would pay for 2 per cent. more energy than was actually delivered to him. In Fig. 63, where the ammeter is placed after the meter, the

loss in the potential circuit is sustained by the supplier of current, and the loss in the fields by the consumer. This is generally the accepted plan for dividing the losses, and is fairer to the consumer than the other method. In Fig. 56 the ammeter and voltmeter are both connected after the meter, and the central station bears both field and potential circuit losses. We have pointed out in previous chapters that the average loss in meters was 15 per cent. of the total amount of current supplied. This being the case, the connection for calibration shown in Fig. 64 will help to eliminate this loss by 2 per cent., and should always be used for this reason in calibrating meters for service. Care should be exercised in connecting the

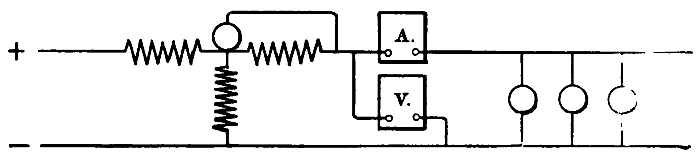


FIG. 64.

voltmeter that its current is not registered by the ammeter. Connections for three-wire meters are modifications of the above. It is assumed that the current to be measured is non-inductive. If an indicating wattmeter replace the volt and ammeter, the series coils of the wattmeter take the place of the ammeter and the potential coils that of the voltmeter.

TESTING IN METER DEPARTMENT.

The outfit for calibrating meters in different stations varies with the degree of importance attached to this branch of the work. It is needless to emphasize the fact that a correct calibration of the meters before they are installed is of the utmost importance.

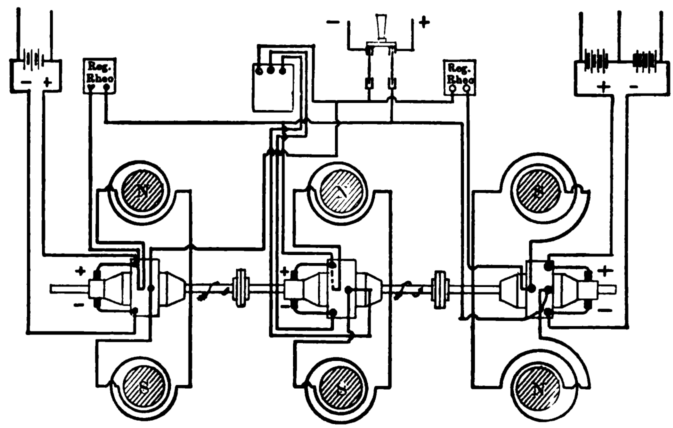
The instruments necessary for the work vary with the class and size of the meters to be tested and naturally divide themselves into two classes, direct and alternating. Direct current testing will be considered first. The usual commercial circuits are distributed at 110, 220 and 500 volts potential.

To measure the energy passing in a direct current circuit by means of an indicating wattmeter it is necessary to take reversed readings, the mean of which is the true reading. It is found quicker to use a volt and ammeter and obtain the product of the readings. If a station is distributing three direct potentials 110, 220 and 500, two standard voltmeters are needed,.one with double scale reading from 0 to 150 and 0 to 300, the other for 500 voltsreading from 250 to 600 volts. The number of ammeters can be limited to two, one double scale instrument reading from 0 to 10 and 0 to 50 in 1–10 amperes and ½ amperes divided respectively, and another instrument reading from 0 to 500 amperes for heavy work.

These instruments should be of standard dead beat type and extremely accurate. The accuracy of all the instruments used in testing should be checked once a week, and oftener if inaccuracy is suspected.

The design and requirements of the testing board vary with the number of meters tested per day, but for any capacity the board should be laid out in such a way as to enable testing to be done as quickly as possible. Before going into the arrangements of switches and instruments a brief discussion of the kind of current to be used in testing is in order. If the station is provided with a storage battery, leads direct from the battery should supply the testing board, so as to avoid the fluctuation of the voltage on the lines. It is customary to charge station batteries at night

from about 12 P. M. to 7 A. M. and let them "float" on the lines in the day time. The leads to the testing board would be at practically the same voltage all day. In event of no battery being installed, leads direct from the bus bars of the plant would furnish a steadier current than the lines, and the voltage could be reduced by inserting a resistance in series with the circuit. Leads from the service mains are the least to be desired, owing to the fluctuation



Gen. 8 volts Motor 120 volts Gen. [illegible] volt

FIG. 65.

caused by varying motor loads. In a well-laid-out system the fluctuation is small, but can easily be 3 per cent. either way and is a source of error because it necessitates guessing at an average value.

A testing system which is by far superior to either of these three is obtained by installing a small storage battery of sufficient number of cells to furnish a three-wire service of 100 to 220 volts. These cells can be quite small,

either of 7 or 10 ampere-hour capacity, as they furnish current only for the potential circuits of the meter. The use of this battery in photometer work is described in Chapter XVI.

The load on the series coils of the meter is furnished by either one or two large cells in series of about 600 ampere-hour capacity, and a normal discharge rate of 75 amperes. The short circuit value of two of the cells in series would be about 300 to 400 amperes. These batteries are connected in series with the field coils of the meter through a variable resistance. The connections for the charging set, switch-board and batteries are shown in Fig. 65.

For storing purposes, this small motor, driving the low voltage generator for the large cells and the booster in series with the line current for the small cells, gives a very neat and effective outfit.

The motor is mounted in between the booster and generator on one bed plate and is directly coupled to each.

The meter testing board if laid out for use with line current must employ either lamp banks or rheostats capable of dissipating large amounts of energy. The system just described uses only about one-fiftieth of the energy consumed by the other method. The variable resistance placed in circuit with the field coils of the meter gives any desired load without in any way affecting the voltage of the potential circuit.

Five-hundred-volt meters can be tested on this battery system by obtaining the fall of potential across the armature and starting coil and applying this voltage from the batteries across this circuit, the field, as in the other low voltage meters, being in series with the low voltage circuit from the large batteries. In effect this test gives the same result as though 500 volts were used.

Before laying out the testing board, it must be decided by what current the meters are to be tested, as great simplification results in using the battery system.

For small stations the expense of a battery outfit would hardly be justified, and, for this reason, a complete testing

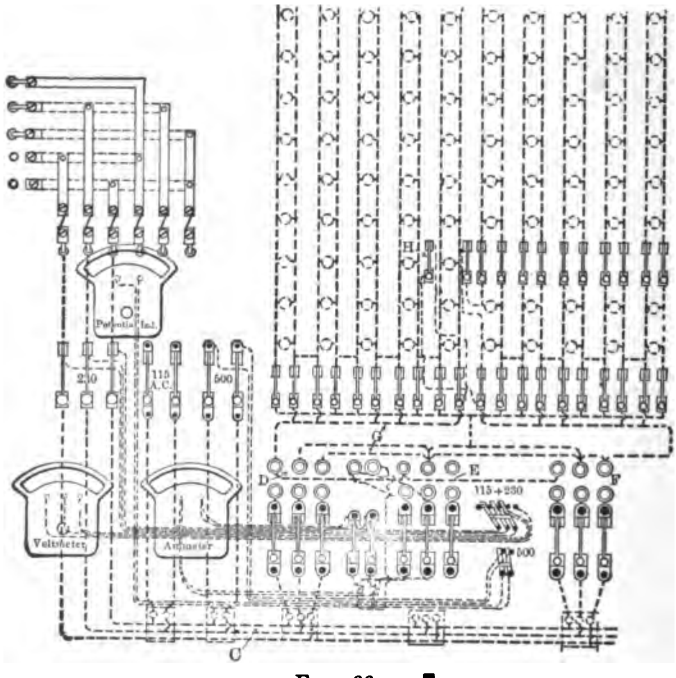


FIG. 66.

board employing one lamp bank for the three voltages will be given as well as a diagram of connections for battery system.

In Fig. 66, we have a three-wire 110 to 220 volt service and a 500 volt, 110 volt *A. C.* and *D. C.* two-wire

service feeding a common three-wire bus *C*. From *C* are let three sets of three-wire leads to a triple row of binding posts at *D*, *E* and *F*. The upper rows of these binding posts feed into bus bar *G*. Single pole switches are inserted in leads from *C* to lower row of binding posts. The bus bar *G* feeds ten rows of lamps which are connected up as shown in diagram, five on each side of the system. The meter to be tested is fed from lower row of binding posts at either *D*, *E* or *F*, and the return leads connected to top row feeding lamp banks. Each row of lamps is provided with single pole switches on each leg, and a tie over switch at *H* enables both sides of the lamp bank to be used on either side of the system. The rows of lamps are fed in such manner that the wires of adjacent rows are of the same potential and are permanently tapped together. The right hand part of the bank is subdivided by breaking the rows of lamps above the second lamp by means of a row of single pole switches.

The great flexibility of this arrangement is apparent, as a two or three-wire meter can be tested from a load of one lamp up to entire load of lamp bank.

In testing on 500 volts, all switches are opened except those at the ends of each five rows. The current then flows in series with five lamps in multiple and up to the full capacity of the bank. This form of lamp bank is very convenient in operation and is cheaper in first cost than two distinct banks for low and high voltage.

The lamps are arranged on the back of the board so as to shield the operator's eyes from the glare and heat. The most convenient arrangement is to have the lamps, switches, etc., mounted on a slate or marble panel, set at the rear edge of the meter testing table.

Fig. 67 gives diagrammatically the connections used with the large and small storage batteries. *A* is field battery, *B* potential batteries, *C* variable resistance in series with field battery, *D* regular type Thomson meter.

As shown the connections are very simple, and need only be modified for testing three-wire meters by placing both fields of the meter in series. It is customary, where a large number of meters are tested daily, to connect up a number of them in series with each other and a carefully calibrated standard meter of the same type. This method is possibly quicker than testing each meter individually, but is liable to several errors which may be overlooked by some.

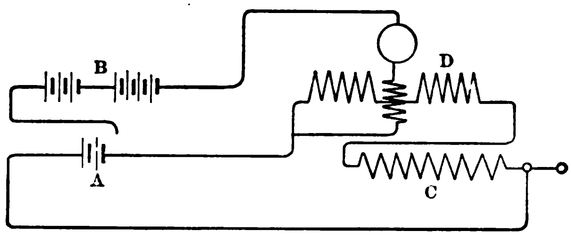


FIG. 67.

When the meters are connected in series, the fall of potential across the fields of the meter diminishes the potential delivered to the next meter by that amount, hence the potential circuit of the succeeding meter operates at a lower voltage than its predecessor; in fact, it will register less by the exact amount of I^2R losses in the fields of the preceding meter. The current consumed in the potential circuit of the succeeding meter is registered on the preceding one, so, as we descend down the line, each meter registers less than its predecessor by the watt losses of the former. If the watt losses at full load be 10 watts, and

10 meters were in series, the first meter would register 100 watts more than the last one. As the load is varied this percentage varies as the I^2R losses in the fields vary, so that, in order to get a correct register, the potential circuits of each meter must be fed separately from the field circuit. This involves disconnecting the potential circuits and feeding them separately, which is troublesome. In the battery systems, where the potential and field circuits are independent in origin, no such trouble exists. The potential circuits need not be disconnected, as they are fed independently by the high voltage battery circuit, which has its positive voltage connected to positive of low voltage circuit in the meter. The individual adjustment of a meter takes as long, whether it be connected in series with many others or by itself; and, as each meter has to receive its individual adjustment, it is no gain in this respect to connect it in series. Meters require a heat-run of from 20 minutes to a half hour to allow the resistances of the potential and field circuit to assume their normal conditions. For this reason, it is a gain to have a number of meters connected in circuit ready to receive their individual calibration. The use of the battery system enables meters to be adjusted with great speed and accuracy. The variable resistance in series with the fields is adjusted to allow a fixed number of amperes to flow. The voltage of the potential circuit is constant and is not subject to varying field strength, as the circuits are independent in origin. For any given ampere value the watts are known and will always be exactly the same for this value; hence, to test the meter, a series of ampere values are taken and the meter speed noted and adjusted. It does not become necessary to make frequent calculations of energy value because it is always constant, the only variable being the load, and that is made whatever

one chooses. In employing only one source of energy, a varying field strength gives a varying voltage owing to the drop in the leads and field coils, and a new calculation has to be made for each change of field strength.

To sum up, it appears that the battery system has a number of advantages over any other, whether the meters are tested individually or in series.

Alternating current meter testing, where a central station employs Thomson meters for both direct and alternating current, may be carried out altogether on the direct current testing board, as the calibration is practically the same for either alternating or direct current.

For induction meters we employ lamp banks, rheostats or motors to furnish a load for the meter. If the load is purely non-inductive, an ampere and voltmeter can be used to measure the energy input, but, as the load may be frequently inductive, it is best to fit up the testing board with indicating wattmeters. In connecting up the meters for various kinds of service, the instructions given in Chapter II must be followed in determining the true watt input flowing through the meter. In other respects the same general rules are followed as given for direct current meter testing.

Testing in Consumer's Premises.

The test of a meter in the consumer's premises is made for either of two reasons: a complaint by the consumer of high bills, or to check the accuracy of the meter for the benefit of the central station. For whatever cause, this test is made in several ways. The merits of all will be considered. The meter may be tested by volt and ammeter, indicating wattmeter, calibrated lamp bank or standard recording meter in series with the meter to be tested. In

testing with volt and ammeter an approximation may be reached, but the method is open to various objections. The fluctuation of voltage on the lines, and the fluctuation of the load in the premises, make it impossible in many instances to obtain more than an approximate test. Especially is this the case where the load is a motor running a shop or direct connected elevator. The man making the test has four moving objects to attend to at one time, ammeter, voltmeter, stop watch and moving meter disk, and the consequence is that he can never be sure that the test is a correct one. On alternating current lines, where the load is inductive, it is not possible to get a correct test by this method unless the exact power factor of the circuit passing through the meter is determined. In practice this is not feasible so the above method is never used. An indicating wattmeter may be used instead of the volt and ammeter, and has the advantage of reducing the number of objects to be watched by one. On alternating circuits, where the load is inductive, the indicating wattmeter is very much used and is the proper thing in testing where the load is not subject to variation.

The third method, a calibrated lamp bank, necessitates the shunting of the service and disconnecting the meter from its load. The lamp bank is composed of lamps of known wattage at known voltages, and the only instrument needed is a voltmeter. The lamp bank is connected to the meter, and furnishes a load with which to test it. If the voltage on the lines is variable, as is likely to be the case where a heavy day motor load is connected to the system, the wattage of the calibrated lamp bank has to be averaged in the same manner that the indicated watt readings were; there is, however, this advantage, that the load is steady. In large installations, where the meter would need at least

the equivalent of 100–16's connected for a test, the lamp bank method is too cumbersome to lend itself readily to economical transportation from house to house. One of the gravest objections to this method of testing is the time and trouble taken in shunting the wiring of a large installa-

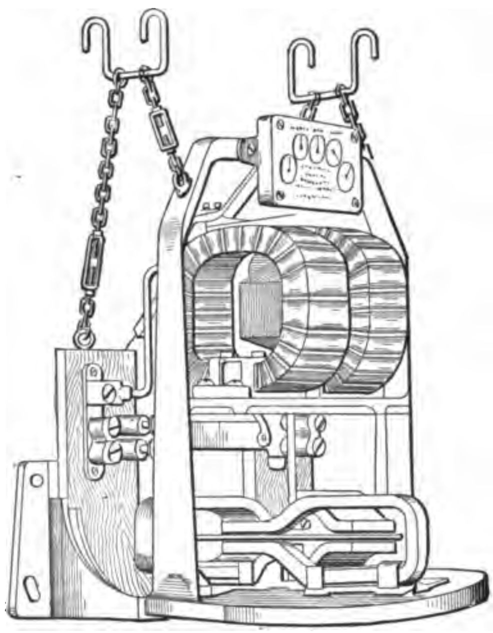


FIG. 68.

tion, otherwise the consumer is cut out of light for a half hour or more.

The fourth method, the placing of a standard recording wattmeter in series with the meter in the premises, permits of an accurate test to be made under any variation of load

and voltage. The standard portable meter is easily rigged up from the usual stock type by attaching chains with turnbuckles to the frame of the meter, in such a way as to allow the standard meter to be suspended from the one to be tested by means of hooks. To properly hang the meter four points are selected on the frame, and chains connected. These lead to a hook on each side of the meter which is used to hang the meter from the one to be tested. A diagrammatic representation is shown. Fig. 68 shows connection of chain and a view of the portable meter as it would appear when suspended from the one to be tested. The meters are then placed in series, and the load in the premises applied. The meter disks are held in the same relative position with reference to a mark on them and allowed to start at the same time. After one or two revolutions it becomes apparent whether the meter to be tested is fast or slow by the relative position of the marks on the disks. If slow, the meter being tested is cleaned, the jewel examined and, if defective, is replaced by new jewel and shaft end, if the parts are accessible. Another trial will show the effect of these operations, and, if still slow, an adjustment of the magnets acting as a drag can be made until the meters run in unison. While this test is being made the operation is entirely independent of any variation in voltage or load as both meters are affected alike by any change in either.

On direct connected elevators and motors of all sorts, this method is the only one which will allow of a correct test being made on the meter with the load which it has to carry.

The ratio of the energy passing through the standard and tested meters varies with the position of the standard meter; that is, whether it is placed before or after the one

to be tested. If before, it receives more energy by the watt losses of the tested meter; if after, less energy by the watt losses of the tested meter, that is, assuming both meters to be of the same capacity and efficiency.

In making a test it is immaterial whether the meters are connected before or after, as long as the watt losses are added or subtracted from the standard. In many makes of meters the watt losses, for practical purposes, may be neglected in making a test.

To make the matter clearer, suppose the consumer has a T. H. meter of five ampere capacity, and the standard portable meter is of five ampere capacity. If the standard meter is connected in front of the meter to be tested, and the watt losses of the two meters on the same load are equal, then, when 500 watts are delivered to the consumer with a 10 watt loss in each meter, we have the following:

520	watts delivered to service side of standard meter.	
4	" loss in potential circuit " "	
6	" " " field " " "	$=I^2R.$
510	" delivered to meter to be tested.	

Assuming the internal losses of the meters to be unregistered, we have the standard meter recording 510 watts of energy and the meter to be tested 500 watts. In other words, on full load the standard would run one-half of 1 per cent. faster than the meter to be tested. In commercial tests a percentage of this magnitude may be neglected, but, as the load decreases, the percentage of error becomes greater as the I^2R losses in the fields become less; that is, on a load of 50 watts the standard meter would receive approximately 4.6 watts more energy than the meter to be tested, or 9 per cent. In adjusting a meter, it is always made correct on full load first and then its efficiency

on one light load ascertained. If the standard meter is connected behind or after the meter to be tested, it runs slower than the one to be tested, and this is bad practice, for this reason. If the consumer is watching the test and sees his meter slower than the standard, he is satisfied that the meter is performing properly; if his meter, on the contrary, runs faster than the standard, no amount of explanation will satisfy him. Therefore, it is good practice to place the standard meter always in front of the meter to be tested.

If the test is being conducted for the consumer, he or his representative usually watches the operation and, if they possess no technical knowledge on the subject, the graphic method of placing two meters in series appeals to them more strongly than when conducted by indicating instruments of which they know nothing.

Again, when instruments are used a stop watch is necessary to catch the number of revolutions accurately, so that we have to contend with the personal error of the observer in reading the indicating meters and catching the time. It is impossible for one man to do this correctly, he cannot watch his instruments and the meter at the same time. Two men are necessary, and the expense of testing is doubled. The series method needs only one man, no reading or calculations are necessary, a variable load or voltage affects both meters alike, the per cent. fast or slow may be ascertained to any degree of accuracy by taking a large number of revolutions for comparison. All of these advantages, and the saving in expense, place this method far ahead of the others.

Meters of 100 ampere capacity and over, owing to the large wires to which they are connected, are troublesome to test and make the necessary connections. On any system the number of such meters on the circuit is a very small

percentage of the whole, and it has been found by experience that the quickest and cheapest way to test these meters is to remove them altogether and replace them by new ones. Suppose in a system of 5,000 meters, 50 of them were 100 ampere capacity and over. To test these meters once a year it would be necessary to change four of them each month; that is, a reserve of four or five meters of different sizes would enable all these meters to be brought back, tested and sent out again.

The sizes of portable meters, then, to be carried in stock are few in number, say five or six. These meters are carefully calibrated before being put in service and are checked before and after each day's work. Their calibration, with proper handling, remaining remarkably constant. The jewel screw is always kept lowered and the disk firmly wedged when not in use.

On a large system of meters, where two or more meter testers are employed, the work is so arranged that each man tests only one size of meter during a day. The tester follows the regular meter routes, and on one day tests one size of meter and the next another and so on, so that the number of portable meters even for a large system may be kept down to one meter for each size.

The desirability of regular meter testing has been proved so conclusively that it need not be gone into, but the question of how often to test is one which varies with local conditions and the kind of meter used. As a general condition twice a year is about right, but in localities where the meters are subject to vibration from heavy traffic more frequent tests result in very material saving in the meter bills.

If a list of the tests made and the amounts saved be kept, such a record enables the question of how often it pays to test to be settled beyond dispute.

The General Policy of the meter department should have two ends in view, the giving of as perfect meter service as it is possible to establish, and the maintaining of harmonious relations with the consumer. Some natural divisions suggest themselves, such as:

1. Should central stations make meter tests without charge?
2. The education of the Consumer.
3. Duties of the Meter Readers.
4. Cleaning meters.
5. Jewel renewals.

1. It has been found by experience that bills complained of are much more easily settled after a test of the meter has been made. This test furnished to the adjuster enables him to know definitely whether the meter is fast or slow and facilitates a settlement in that way. From the viewpoint of cost to the central station it averages about 50 cents to test a meter in the premises, and, as the meters as a rule are slow, the adjusting of the meter to run correctly more than compensates for the cost of the test. As an economic practice, the testing of meters for consumers is desirable, and under no circumstances should they be discouraged by charging for the test. The writer has had occasion to change his views on this point within the past two years since collecting data on the subject, which data showed conclusively that the central station saves many times over the cost of testing by adjusting the meters to run correctly. The manner in which the record is kept is detailed more fully under "Records" in this chapter.

2. The widely extended use to which electricity is put in every branch of life is gradually lessening the general

ignorance of the public on electrical subjects. The majority are still wrapped in profound ignorance of the simplest fundamentals, and the meter to such people is a wholly mysterious, eccentric and untrustworthy piece of apparatus.

It would be a useless effort to try to educate the consumer in the principles upon which his meter operates, but he should have a knowledge of the manner in which his bill is determined. Many of them can read the dials correctly, but cannot figure out the bill from the readings. An excellent method of placing in each consumer's hands the knowledge of how to arrive at his bills is to get up an instruction card, showing a dial with a sample reading thereon and go through the process of getting the bill. This card can be mailed to each consumer or left by the meter readers, and, as a result, the consumer's curiosity is excited to know the amount of his bill, and he tests his meter by the dial to find out whether it is correct. The better he comes to know the meter, the more respect he has for its correctness, and fewer complaints are turned in of "high charges." If we could conceive of the condition of every consumer being able to read and test his meter, the complaint adjuster would have very little to do, as then only the real errors would be brought in.

The results from distributing the instruction cards have been found very beneficial in practice, both in the education of the consumer and in establishing better relations.

3. The duties of the meter readers are not confined to simply taking off the position of the dial hands. It is the commonly accepted idea that cheap labor should be employed on this work, and its duty confined to the mere taking of the reading. If this practice be followed, it becomes necessary to employ inspectors to examine and

clean the meters at regular intervals if an efficient meter service is the end sought. The cost of meter readers and inspectors to the central station is greater than if the offices of the two are combined by making the meter reader an inspector as well.

4. The practice of giving the meter a thorough cleaning once every two months cannot be too highly commended, and if the meter has commutator and brushes, the passing of a piece of linen tape between them and pulling briskly back and forth gives a high polish which reduces friction. At the same time that the meter is cleaned the jewel is examined and, if defective, renewed as well as the removable shaft end.

5. The life of a jewel varies with the treatment it receives. Vibration and dust tend to shorten this life, and if the vibration be excessive it becomes extremely short. However, outside of the effects of vibration and dust, the life of a jewel has a somewhat definite period, after which it rapidly deteriorates. In order to avoid the evil effects of letting defective jewels remain in the meter, introducing a friction which causes a direct loss of revenue, it is evident that some definite system of jewel renewals must be instituted. If a meter contain a defective jewel there is no economy in letting it remain in the meter, and the condition of meter service in which no defective jewels are allowed to remain in would certainly be far superior to any other. Therefore, when the meter reader cleans the meter at periods of two months apart, if he renews the jewel at the same time, he eliminates the loss due to defective jewels. He need not test the jewel to see if it needs renewing, after the system is instituted the old jewel is taken out and the new one put in, the old jewel being tested after it is brought back to the meter department. The good

jewels are sent out again; the defective ones discarded. In this way nothing is wasted, and the bad jewels are effectively weeded out of the system. The meter reader's duties then are to read every meter on his route, to inspect, clean and renew jewels in every other meter. The greater part of the time taken in reading is consumed in getting from meter to meter, the actual time of taking the reading is small; hence, the cutting down of the route owing to the extra time consumed in cleaning every other meter is not as great as appears at first sight. If a reader on a given route can read 100 meters per day, on the same route he can read 75 meters and clean every other one, the reduced distance by leaving off 25 meters more than compensates for time taken in cleaning 37 meters.

As a concrete example, suppose a central station employs four meter readers and three inspectors, the inspector cleaning and renewing jewels once every two months, the addition of two more inspectors would take the place of four meter readers and a much more efficient service secured. In other words you eliminate the going over of the same ground by different men for different purposes, and secure better service at less expense by combining their offices. While cleaning the meter a rough test can be made of its correctness on light loads; in this way many defective meters are replaced to advantage by new ones.

The examination of the meter loop to see that the customer's installation is all recorded, and the lookout at all times for ways and means of beating the meters, are among the many if lesser duties of the readers. A good meter reader must be alert, intelligent, courteous. It pays to employ good men for any service, it pays particularly well here.

CHAPTER XIII.

Reading Meters.

Meter reading is a simple operation, yet many fail to grasp the relations of the hands of the dials to one another, in such a way as to avoid making mistakes in taking a reading.

The majority of meters have five circles composing the dial face, and each circle is divided into ten divisions. Under or above each circle is marked the amount of energy each one indicates in a complete revolution. These units are usually expressed in watt hours, and the lower right hand circle is usually marked "1,000 watt hrs.," indicating that one revolution of this circle registers 1,000 watt hours, and each division in it 100 watt hours. The next circle, reading from right to left, will be marked 10,000 watt hours, and so on in multiples of ten to the last circle at the left hand side of the dial face. Therefore, reading from right to left, each circle indicates ten times the amount of its predecessor, hence, each division on a circle indicates an entire revolution of the preceding one. If this relation be borne in mind it is almost impossible to make a mistake in reading the meter, even if the hands be slightly misplaced. The hands on the first, third and fifth circles turn clockwise, and on the other two counter-clockwise, which leads to confusion with a beginner when first attempting to read a meter.

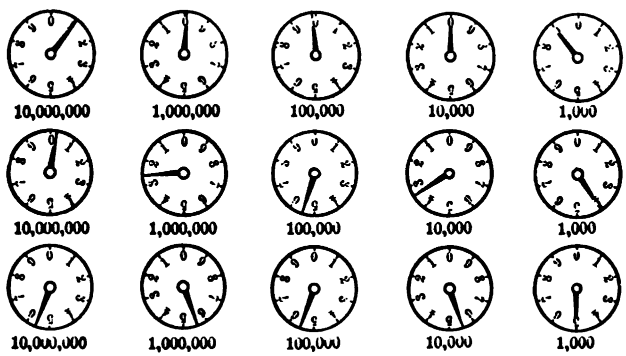
The reading is started with the dial indicating 1,000 watt hours and the indication of the hand put down at the nearest 100 watt hours. The second circle is likewise marked down, the number being placed to the left of the

first circle's indication. The third, fourth and fifth dials are likewise recorded.

The relation of the dials to each other must be borne in mind when reading, and it must be remembered that, when a hand stands between two numbers, the one last passed is the one to record.

The subject can be better explained by means of examples, a few of which are herewith given.

In Fig. 69, we have 900 watt hours registered as the first circle and the hand of the second dial apparently on 0. It is evident that this cannot be on zero, as the space from 9



FIGS. 69 (TOP ROW OF DIALS), 70 (MIDDLE ROW) AND 71 (BOTTOM ROW).

to 0 represents one whole revolution, circle 1; hence, we read this 9,900. In dial 3, the hand is again on zero, but it cannot be actually zero as the previous dial did not complete a whole revolution, therefore we read it 9, and the reading stands 99,900. Circle 4, is read 9 in the same manner and the total reading is 999,900. On the fifth circle the pointer is on 1, but, as dial 4 did not complete its revolution, we read this zero. It is very easy for any one not bearing in mind the relation of the different circles

to each other to make this dial read 1,000,900 watt hours.

In Fig. 70, we have a very easy reading—253,400 watt hours, and in Fig. 71, a succession of 5's, making a reading 5,555,500 watt hours. As 1,000 watt hours is one kilowatt hour, the total indications of the dial face with multiplier 1 is 10,000 kilowatt hours.

After one becomes familiar by practice with reading meters, the dials may be read from left to right with facility, but the safer way is from right to left. Nearly all meters have multipliers in the larger sizes by which the indication on the dial face is multiplied to obtain the number of watt hours that has been used. In some of the small sizes, the indication of the dial face is multiplied by a fraction to obtain the true watt hours.

Some manufacturers, instead of using a multiplier for different sized meters, change the relation of the worm gear reduction between the dial train and the revolving armature shaft in order to make the dial face always read directly in watt hours. This practice is to be commended, as it tends to simplify the records and eliminate errors by getting the wrong multipliers recorded through oversight.

Ampere hour meters have dial faces which indicate ampere hours instead of watt hours. The readings are taken in the same manner as described for watt hour meters.

The majority of consumers of electric current, particularly store keepers, mill owners and factories, would like to know how to read their meters and figure out the bills from the readings. A knowledge by them of their daily consumption of current would enable them in many instances to institute economies which would result in a material reduction in their lighting or power bill.

We will suppose, foı example, that the reading of the

meter on May 1st was 986,600 watt hours, and on May 10th it was 1,230,600 watt hours, the consumption of current for the ten days would be 250,000 watt hours, or 250 kilowatt hours. To obtain the bill, the kilowatt hours are multiplied by the amount charged per kilowatt hour which we will suppose to be 10 cents. Twenty-five dollars ($25.00) would be the required bill. If the dial face carried a multiplier, the consumption would have been multiplied by it and then by the price per kilowatt hour. Whether for light or power the bill would be determined in the same manner.

As a 16 c. p. lamp, when burned for one hour, registers 50 watt hours on the dial face, a rough estimate can be readily made by the consumer to ascertain the correctness of his meter. If ten 16 c. p. lamps are turned on for one hour, the meter will register it correctly, 500 watt hours. A percentage fast or slow would be readily noticeable in a reading of this size, and the consumer in this way can satisfy himself as to the correctness of his meter. If this were more universally done, much idle complaint by the consumer would be avoided.

To facilitate the duties of the meter reader, a meter slip carrying blank dial faces is used, and the indications of the hands are marked down as they appear. This serves as a check on the reading recorded, and enables a "checker," when the slips are turned into the office, to verify the correctness of the reading. After a dial face has been in use for some time, the fifth circle at the left hand may complete a total revolution between readings. In that event, the previous reading is subtracted from 10,000,000, and the reading found on the dial when read will be added to the amount thus obtained. In other words, the dial will have started all over again. This frequently happens, and sometimes leads to confusion in the mind of the consumer.

CHAPTER XIV.

Value of Losses in Meters Relative to Income.

The meter has been one of the most potent agencies in the development of the central station for the distribution of electrical energy for light and power purposes, but the history of this development is interesting from many standpoints.

Steam engines and water wheels have been brought to ever-increasing heights of efficiency, due in great measure to the exacting conditions imposed in the various classes of central station duty. In the past few years, the gas engine and steam turbine have been perfected to such a degree that they bid fair to dispute in some measure the claim for first places as prime movers with the steam engine.

On the purely electrical side, the rapid growth of the dynamo and motor both in size and efficiency, and the many uses to which the latter is put, have divided the field into many provinces, distinct, yet united by their common ancestry.

The no less rapid perfection of the arc and incandescent lamp has ever widened the lighting field, until to-day electricity holds first place as the illuminant of the world. In the early days of electric lighting, when the commercial side of the problem was first attacked, it was recognized that the broad principle upon which the commerce of the world is carried on constituted the only equitable and profitable basis on which lighting could be done; namely, the paying for exact value received. In commercial life

we meter every product that is sold either by weight, measure or some known standard. It is unnecessary, however, in ordinary transactions to do this automatically, or to still further complicate matters by bringing in the element of time. The commercial measurement of electricity, as we have seen, must combine all of these factors, and many hundreds of patents testify to the work which has been done along these lines. The idea of charging so much per month for 16 c. p. lamp installed was a crude one, but examples of it are still found in many communities. The lamp then becomes a crude meter, and at the first glance it is seen that this is merely an approximate way of securing an income and gives rates to different consumers which vary over wide ranges.

The failure of many plants to earn dividends was directly traceable to this method of selling current, and, except where the load and hours are fixed quantities, it is universal modern practice to meter all installations whether for light or power. But the mere fact of placing a meter on a circuit does not insure immunity from loss to the central station; the meter needs care and proper attention, otherwise its readings are not a true record of the current consumed in the circuit.

In the general consideration of the various engineering problems of central station management, the meter is usually relegated to somewhere near the tenth place in matter of importance. Its use is well recognized, but the necessities of its maintenance and operation are usually neglected, until to-day it is the least understood of all branches of electrical engineering, even by those who are acknowledged authorities.

It is easy to build a meter having a commercial efficiency of from 98 to 99 per cent. on half and full loads, and, at first

glance, this appears to be a very creditable performance, but the question is—what will this same meter do commercially on from 2 to 10 per cent. of its load?

The average load on the meters of a central station lies, as a rule, under 10 per cent. of their capacity; this fact emphasizes the extreme importance of having the meters register correctly on this load.

In taking up the discussion of the losses in the meters and their relations to income, it is necessary to outline in a general way the main factors of cost of generation and sale of current from a central station.

The three main factors necessary to secure the successful operation of a central station are: 1st, Never failing integrity of service; 2d, A market for the current; 3d, Proper registration of current sold. The first and second of these factors will be assumed to exist. They lie outside the scope of this discussion, and may be considered as the prime requisites of any commercial undertaking. On the purely operative side of the business, the management of the meter department easily stands first in its effect on the economy of the selling of current from central stations. The details of this management are set forth in Chapter XII. The cost of current to the central station is determined by its operating expenses and fixed charges per unit of current generated. The fixed charge, after the investment is made, remains a fairly constant factor per unit of current generated, hence economy in operating expenses becomes the chief end of the central station manager. It is necessary, for the sake of brevity, that we accept the conditions which we find prevalent in the actual cost of generation of current without going into details. In this connection a brief summary of what is considered fairly representative cost in the art,

as it is to-day, will be given. The cost of generating a kilowatt hour varies with the locality, cost of fuel, etc., but the range may be taken from one-half to one and a half cents per kilowatt hour at the switchboard. It is assumed that the plant is of modern construction, with compound or triple expansion engines as prime movers, and having the usual auxiliaries pertaining to the best modern practice. Under such conditions one-half cent per kilowatt hour would represent extremely favorable conditions and one and one-half cent per kilowatt hour good conditions, so that an average of one cent per kilowatt hour may be taken as a basis of cost for the purpose of showing the relative cost of generation to income in contrast with the meter loss to income. In assuming one cent per kilowatt hour as cost at the switchboard it is necessary to assign values to the various items which go to make up this total, so as to show what percentage the different items of cost bear to income.

Fuel will be taken as three pounds per kilowatt hour at $2.00 per ton, making the cost for fuel per kilowatt hour .0033 cents, leaving .0067 to represent labor, maintenance, oil, etc.

Let us assume an average daily output of 30,000 kilowatt hours, and the usual line and meter loss of 25 per cent. between the bus bar and the total amount registered at consumer's. Let us assume, also, an average net price of ten cents per kilowatt hour as registered by the consumer's meters. Then the net price at the switchboard is 7½ cents per kilowatt hour. From the above, the ratio between the cost of coal and the net amount received per kilowatt hour is roughly 1 to 22, or the cost of coal is only 4½ per cent. of the net income.

Any loss or saving in the coal pile of from 10 to 20 per cent. only effects the net income by a fraction of one per cent.

Under the conditions assumed, the total cost of generation is 13⅓ per cent. of the net income, and, even if the most rigid economies permissible to good practice were instituted, and the cost per kilowatt hour reduced thereby to .75 cents, a saving of only 3⅓ per cent. of the net income would be the result.

It is the writer's intention, not to belittle any practice which reduces the cost of generation, but merely to point a comparison between those losses and a loss which is in excess of their total; namely, the loss in the meters themselves.

It may be safely stated that in a carefully operated central station the net saving in generation, which could be effected by the most rigid economies, will not exceed 3 to 4 per cent. of the net income. Any saving in the cost of generation is limited in extent; that is, can never approach closely to its limit in the present illustration of 13 1-3 per cent. of the net income.

In taking the total loss in lines and meters at 25 per cent., the average condition of the large central station in America is represented. The usual loss attributable to meters is 15 per cent., and 10 per cent. is the usual line loss. The loss in transmission from the switchboard to the consumer will be made as large or small as we please, according to the amount of copper used in distributing the current. The 10 per cent. loss in the lines means that the generating equipment must be 11 per cent. larger than that necessary to meet the demands at the consumer's connection.

Any reduction in line loss means larger copper investment, any increase in line loss means larger generating capacity, so that there is established somewhere an economical balance which varies for different conditions, but

may be roughly taken as corresponding to a 10 per cent. loss in the distributing system.

This line loss of 10 per cent. in the example given above means that only 27,000 kilowatt hours are delivered to the consumer, of which only 22,500 kilowatt hours are registered after the 15 per cent. meter loss is deducted.

The line loss should be included in the cost of generation, since, if the line loss be reduced, a reduced amount of current is generated at a reduced cost, and vice versa.

The meter loss, on the contrary, is in current actually delivered and used by the consumer, but not paid for by him.

The loss is of such a nature as to affect the dividend directly by its amount. The general expenses of the plant and system are not altered whether it is prevented or not. It seems incredible that a loss of this magnitude, the prevention of which would effect a saving that would offset the entire cost of generation, should be tolerated.

The peculiar conditions prevalent in central station practice bring about a condition of affairs which is very trying to the correct registration of current. The meter capacity installed usually equals the load connected to the lines. The maximum output of a central station feeding a distributing system for light and power rarely exceeds 20 per cent. of the load connected. The minimum output falls as low as 2 to 3 per cent. of the load connected, or the meter capacity. Thus it is evident that the meters, as a whole, register on from 2 to 20 per cent. of their rated capacity, the mean load falling as low as 6 to 10 per cent. of their capacity.

When the problem is looked at broadly in this light it is not difficult to see why a meter having a high commercial efficiency on half and full loads fails to register properly on a mean load of from 6 to 10 per cent. of its capacity.

As an example of the trying conditions under which meters work, let us take a store having 100–16's installed. During the day, from 7 A. M. until 4 P. M., assume that 2–16's are burned, and that from 4 P. M. to 6 P. M. an average of 50 lights is used. After 6 P. M., until 7 A. M. next morning, one light is left burning. If the current were correctly registered, the amounts for the different hours would be as follows:

7 A. M. to 4 P. M.	9 hours at	$0.02	$0.18
4 P. M. " 6 "	2 " "	.50	1.00
6 " " 7 A. M.	13 " "	.01	.03
			$1.31

In commercial practice a meter of 100 light capacity does not register one or two lights with any degree of accuracy, in all probability not running at all on one light. The loss, in this instance, per day on the small burning of 31 cents would be, say, 25 cents or 18 per cent. of the amount registered. This case in hand represents a prevalent condition. There are exceptions where the meter is always run at a load in which it is practically correct. Again, the conditions may be easily more adverse. At any rate, they are sufficiently adverse to cause a general loss of 15 per cent. of the current delivered, and that too by meters which, on loads of 20 per cent. of their capacity, are commercially correct.

The solution of this problem would be one of the greatest

benefits to central stations. That solution so far has not been reached by any meter on the market, but manufacturers are constantly bringing out improved types of meters with higher light load efficiencies and a general improvement may be looked for in a few years when the older types of meters wear out and are discarded.

CHAPTER XV.

Differential Rating.

Electric current is charged for at so much per unit, with discounts of varying amounts applying to the different number of units used in a specified time. A careful study of the load line of a central station reveals the fact that between certain hours of the day a great deal more current is used than at any other time. A plant must be installed which will be capable of meeting the larger demand, and this means that it will lie idle for a great part of each day.

The investment in this required generating capacity, which is only used for a short period, increases the cost of furnishing current during the hours of "peak" over that of the normal load. However, by charging a uniform rate per unit for each 24 hours, an average rate may be struck which will yield a profit on the business done.

The plan of differential rating has secured quite a strong foothold, and the theory of it has been worked out along two distinct lines,—one to make the maximum demand of the consumer at any time during the month a basis of rating his charge per unit, and the other to charge at a higher rate per unit for current used in the hours of "peak."

The Wright demand meter is the best known device for the first method of differential rating. The principle of the recording thermometer is used, and the instrument consists of a U-shaped glass tube with a bulb at each end, partly filled with sulphuric acid, and hermetically sealed.

On the upper bulb a strip of platinoid is wound, this platinoid strip is placed in series with the current flowing, and is heated thereby. The heat generated in the strip expands the air in the bulb, and forces the liquid up the other leg of the U into the remaining bulb, where it overflows into a recording tube which is graduated to represent amperes flowing. The instrument can be reset by allowing the liquid to flow from the indicating tube by tilting the instrument. The origin of the system was in Brighton, England.

The demand meter is placed in series with a recording wattmeter, and the total number of watt hours registered is checked against the maximum demand to determine the number of hours per day that the maximum demand was used. Whatever the comparison in the case, the length of time per day that the consumer could have used his maximum demand is noted and the charge adjusted. The number of hours of high charging are usually varied in summer and winter, say a half hour per day in summer and one to two hours in winter. The remainder of the amount registered is charged for at a reduced rate. The indicator will not record short circuits or demands of only a few minutes, but takes fully ten minutes to indicate its load.

The idea is to make each consumer pay for his proportion of plant investment necessary to meet the peak of the load he uses. In other words, if the consumer use the same amount of current each hour of the 24, a minimum plant investment with a maximum return would be the result. If the total energy generated in 24 hours were used in 12 hours, double the generating and line capacity would have to be installed to get the same revenue. If the consumer use current for one hour per day to the same amount that his neighbor does in 24 hours, the plant

investment for one would be 24 times as great as for the other, and the same revenue would be derived from both.

But the weak spot in the Wright demand system is that the consumer does not lend himself readily to the solving of central station problems, and prefers to buy electricity at a fixed price per unit. Again, it is no inducement for a consumer to burn light when he does not need it, no matter how cheap it is.

A modification of the Wright demand system was put on the market by Edward Halsey, of Chicago. The advantages of his device lie in doing away with an additional resistance in circuit with the line and in its adaptability to either two or three-wire meters. In a recording meter having a magnetic drag, the armature shaft is cut in two parts and connected by a sleeve and ratchet coupling. The upper portion of the shaft carrying the armature carries a pointer which travels over a graduated scale laid off on the meter disk. The upper and lower portions of the shaft are coupled by a graduated spring which allows the pointer to assume a position equal to the torque on the armature. When this torque is removed, the ratchet prevents the pointer from traveling back to zero, thus leaving a permanent indication of the maximum demand. A viscous fluid is placed in the sleeve which retards the movement of the shaft in such a manner as to prevent the pointer from recording momentary overloads or short circuits.

The principles of rating in this and the Wright systems are the same, the difference lying only in the means used for obtaining the maximum demand.

Another system, which does away with any device at all, is based upon the assumption that the maximum demand will be the consumer's installation or some known

percentage of it. This system is limited in its application and is not at all suitable for stores or warehouses where a large number of lamps are installed, but is applicable where only a small number are used. The rating is the same as in the Wright system.

The two-rate meter placed on the market by the General Electric Co., affords another system of differential rating with a different theory at its base. The meter carries two dial trains and a self-winding clock for switching over clutch mechanism at suitable hours for throwing the different dials on or off. For instance, if "the peak" lie between the hours of 5 and 7 P. M., one dial is used to meter all the energy consumed during these hours and the other dial that consumed in the other 22. Such a system can be carried out successfully from a mechanical standpoint, but the effect of the practice has been to drive the consumer to using some cheap illuminant during the hours of high charging.

It is true that long hour burning is encouraged by the cheaper rate given during the day and latter part of the night. The consumer's peak may not correspond with the station peak, and if such be the case, the principles of the demand system are violated, as the consumer fails to pay in proportion to his plant investment.

It is not believed that differential rating is a permanent solution of the problem of charging for current. If every consumer were an electrical engineer and were willing to abide by his faith in differential rating, the scheme would be extremely practical and just; but as such is not the case, and as every other commercial problem in the law of demand and supply has its peaks which are worked out on a fixed rate of charge instead of differential rate, he demands the same with regard to his use of electric current.

If a differential rate scheme be adopted, it is necessary, in order to avoid the errors of the system already named, to secure a complete load curve of the consumer's burning each day.

A device that would take the total number of watt hours registered for a given period and break it up into its component parts, telling how long the maximum load was on, how long the minimum, and also when no lights were burned at all each day, would give a complete load curve of the consumer's burning and furnish a perfect basis for differential charging. A chart ammeter in series with the meter would answer the purpose, or preferably still, an integrating movement attached to the dial train. The integrating movement attached to the dial train would be worked in conjunction with a clock and a pointer, actuated by a cam on one of the dial spindles, made to dot off any given watt hour unit consumed in a certain time.

Any auxiliary device increases the meter investment and also the clerical work, and all of these things must be taken into account in the consideration of differential rating. The problems to be solved for any central station are these:

The average cost of generating a kilowatt hour.

The saving that would be effected by the installing of storage batteries and the leveling of the "peaks" in the load curve as against the maintenance of these peaks and differential rating.

The installing of storage batteries has the two advantages of leveling the load line and making the cost per kilowatt for each hour of the day the same.

If differential rating be used to secure the proper income, the cost of generating a kilowatt hour remains the

same and we have a very unsatisfactory method of obtaining an income. While the general scheme of differential charging is to discourage the peak burning, nevertheless it remains and always will remain as long as the contrasts of night and day exist.

From a careful consideration of all the conditions, it appears conclusively that the ultimate solution of the basis of charge must follow in the lines of general commercial practice; a fixed rate per unit.

In large communities, such as our cities of New York, Boston, Chicago, Philadelphia, the whole trend of the age is towards consolidation. The railroad and electric interests are frequently affiliated if they do not actually belong to the same people. The current for an entire city may be furnished from one plant or group of plants so arranged that each individual plant is worked to its highest efficiency.

The ever-growing uses to which electricity is put are evening up the load curves, and the individual ceases to become a short hour burner. The man in his home uses electricity; when he rides down town to the office he uses electricity; at the office, lights and fans contribute to his comfort; when he goes to dinner he rides on the car again. After dinner he dresses by electric lights to go out to the theatre or club, or if he stays at home he still uses electricity. If he keep an automobile, it is charged from 12 at night to 7 A. M., so we find the individual practically a 24-hour consumer of electric current. This current is all furnished by a number of individuals, A. B. & C., associated together in a company. It is a matter of engineering ability to determine whether it pays in any given set of conditions to even up the load line in a plant by means of storage batteries, and this question is for A. B. &

C., to decide. The individual claims he is a long hour consumer and entitled as such to the best rates, and therefore is not called upon to help finance the investments of A. B. & C., other than to purchase current at a fixed price. In the general plan of electrical development it does not pay to discourage the consumer from using current at any hour of the day, but rather he should be encouraged to use all he can at any hour. If told that between the hours of 5 and 7 in the evening A. B. & C. find that, owing to poor engineering, they are unable to furnish him with as much current as they would like and will have to charge a higher price at these hours, in order to discourage its use, the consumer naturally rebels. The consumer has worries of his own, he does not care to be eternally bothered about his use of electricity, but wants to purchase current at a fixed price per unit as he does every other commodity he uses.

Differential rating is a temporary makeshift which is bound to go before the demands of the consumer for a fixed price per unit. This has been recognized by a number of the best managed plants in this country, and all schemes for differential rating are avoided as being impractical and cumbersome.

We cite, as an instance, the policy of New York Edison Company, which has for a number of years steadily decreased the price per unit with increased demand, and has successfully carried on a large and lucrative business on the basis of fixed charges per unit.

American practice has been slow to take hold of the differential rate idea, although a number of large plants are using "Wright" meters on their systems with more or less success. From the trend of the times it may safely be predicted that within ten years' time the differential rate will be a thing of the past.

CHAPTER XVI.

Elements of Photometry.

The 16 candle-power lamp was, as it is yet, to a great extent a meter. The flat rate system uses the 16 candle lamp as a basis of charge on a supposed number of hours burning. It is recognized that this is a very crude way of metering current, as the factor of time, one of the most important elements, is unrecorded. The metering or measuring the candle power of lamps is a determination of their efficiency as regards consumption of current per candle, as well as the mere determination of their candle power. Hence the measuring of candle power is closely allied to measurement of current and is properly included in the same discussion.

The measurement of light offers many difficulties not encountered in the measurement of such things as time and weight. The candle is the unit to which light intensities are referred. The origin of this unit was quite natural, as the candle was one of the earliest and most uniform of light-giving sources.

But this unit, while approximately constant, is subject to considerable variation, according to the size of wick, quality of the fuel and height of the flame, besides the influences of atmospheric conditions. The standard English candle is supposed to give unit light with a flame 1.8 inch high, and a consumption of 120 grains of material—spermaceti and wick—per hour. The difficulties of obtaining a correct reading from such a standard are great and have led to the seeking of various standards, all of which

are more or less open to objection. Some of the best known of these may be briefly mentioned without going into a detailed description.

The pentane lamp has many excellent qualities. Pentane is a refined distillate of gasolene, and in its pure state is an excellent fuel for a standard light-giving source. The difficulty of obtaining it in a pure state is so great that it has been practically abandoned as a standard. The pentane is fed by a wick to the flame, which burns inside a metallic chimney having a slit and a gauge for indicating the height of the flame.

The Methven screen arrangement, one of the well-known secondary standards, consists of an argand gas flame burning inside the usual glass chimney. On the outside of the chimney there is placed a metallic screen with a slit which allows a light intensity of two candles to pass. The flame burns at a height of three inches. The varying quality of the gas is the greatest objection to this light as a primary standard, although it may answer very successfully as a secondary standard.

The Hefner-Alteneck lamp, burning pure amyl-acetate, fulfills more fully the requirements of a reliable standard than any other known standard, and has been adopted provisionally by the American Institute of Electrical Engineers as the best candle-power standard yet obtained. For a more detailed description of this and the other standards, the writer takes pleasure in referring the reader to a series of articles by Prof. Wilbur M. Stine, in the March, April and May (1899) issues of the *American Electrician.*

Our appreciation of the intensity of light is at present confined to one organ, the human eye, and as every eye has its own particular "personal equation," the comparison

of light intensities with any standard must vary by an appreciable per cent. according to the observer. Hence, when we speak of the "candle-power" of any source of light, it is more or less a comparative term.

There are, then, two sources of error to contend with in the measurement of light, a variable standard and the personal error of the observer. In spite of these difficulties the commercial measurement of various light sources has reached a stage where the error amounts to an insignificant percentage.

A few years ago we rarely heard of the photometer outside of a laboratory. The advent of the incandescent lamp has been the cause of the familiarization of this instrument. There was little need commercially to measure the candle-power of a gas or oil flame; the light-giving qualities of the one are fixed by the size of the orifice of the burner, quality and pressure of the gas; those of the other, principally by its size and the condition of the wick. The deterioration of the candle-power of a gas flame is dependent primarily on the source of supply, while that of the incandescent lamp, assuming the voltage constant, depends upon its age. This decrease in illuminating power, due to aging, it has been the chief desire of manufacturers to overcome. Their degree of success will be brought out more fully later. It is apparent that if the modern incandescent lamp remained of a constant light-giving quality, the factory test would be all that would be needed to establish its candle-power until it was burnt out, and that the deterioration of the candle-power with age is the chief cause of the development of the commercial photometer.

An incandescent lamp of low efficiency can be made, however, which, when properly aged, will remain

practically constant in candle-power if burned at the proper voltage. Such lamps are tested by a primary standard in a very careful manner, and can then be used as secondary standards with a fair degree of accuracy; hence the use of oil and gas flames as secondary standards has given place to a properly aged and tested incandescent lamp. This practice has many advantages besides ease of manipulation in testing, the chief of which are slow deterioration of the

FIG. 72.

standard and the same character of light as the lamp to be tested.

The commercial photometer with an incandescent standard is very simple and lends itself readily to the unskilled handling which it frequently encounters. Two excellent types of photometers designed for the commercial testing of lamps are the Queen Standard photometer and the Deshler-McAllister instrument, both well

suited to the needs of the central station. Both of these photometers were designed to supply the need for a rapid and fairly accurate instrument. In photometers of this class the time element of a lamp test is the most important mechanical factor connected with the instrument, affecting directly also its value as a commercial success.

The Queen Standard photometer, which is represented by Fig. 72, consists of two cast-iron pedestals carrying a rack on which are mounted the photometer carriage and scale. The carriage is rolled to any desired position and

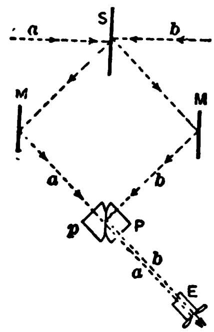


FIG. 73.

the reading taken directly from the scale. Two styles of screens are used, the Lummer-Brodhun and Bunsen. The former is about three or four times more sensitive than the Bunsen, but the latter may be read more quickly. Either may be used, but when the number of lamps to be tested is very large, the Bunsen, owing to its quick manipulation, has much to recommend it.

The Lummer-Brodhun screen consists usually of an opaque piece of gypsum and a set of right-angle prisms with their hypothenusal faces partially coinciding, and

mirrors so arranged as to reflect the light from both sides of the screen, as indicated in Fig. 73, where S is the screen, M, M, the mirrors, and P, p, the prisms. One prism, p, transmits the light and the other, P, reflects it, giving a double field of light which is viewed through the telescope at E. The two beams of light are lettered a and b. If they be of unequal power, the two "fields" of light present a marked contrast, and only become the same when both sides of the screen are equally illuminated. The field is a

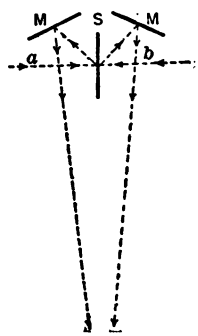


FIG. 74.

round spot and that of b is a ring surrounding this spot. The contrast is so marked that a balance can be obtained with great nicety.

The Bunsen screen, represented diagrammatically by Fig. 74 is probably more familiar, consisting simply of a piece of opaque paper, S, with a grease spot on it. Two mirrors, M, M, are set at such an angle as to reflect this spot and allow the observer to judge of the relative intensities of the fields on opposite sides of it. When the spot appears of equal strength in both mirrors the screen is

receiving the same illumination on each side, and the candle-power is read directly from the scale.

The left-hand pedestal carries the standard lamp, in series with which is a regulating rheostat to enable it to burn at the exact voltage at which it gives 16 c.-p. The right-hand pedestal carries the lamp to be tested, mounted in a revolving socket. A special arrangement allows the lamp to be put in or removed without stopping the socket. A controller permits the socket to be run at the desired speed of 180 revolutions per minute. An adjustable rheostat is also in series with the lamp to be tested, allowing the voltage across the lamp to be made anything desired within a small range. Between the pedestals is placed a table upon which rest two voltmeters and an ammeter. One voltmeter is connected across the terminals of the standard lamp and the other across the terminals of the lamp to be tested; the ammeter is placed in series with the tested lamp. One voltmeter may be dispensed with by putting in a throw-over switch, connecting the two lamps to one voltmeter and taking readings on each alternately.

The Deshler-McAllister photometer, manufactured by the Electric Motor and Equipment Company, is made in the portable form, but, when equipped with a rotating socket and mounted on a table or bench, it becomes suitable for station work. (See Fig. 75.) The instrument is about five feet long and can be folded up. The working standard of light is a duplex oil lamp at the right-hand end of the instrument. This lamp is lighted and allowed to burn 20 minutes; then it is calibrated by a standard incandescent lamp. Calibration is effected by placing a standard lamp in the socket which the tested lamp occupies, placing the screen at the 16 c.-p. mark on the scale, and adjusting

the oil flame until a balance of "fields" is effected. The screen is of the Bunsen type, riding over a celluloid scale on which the candle-power is marked. The station type of instrument is now fitted with a rotating lamp-socket at the left-hand end and an ordinary lamp-socket at the right, the oil lamp being dispensed with.

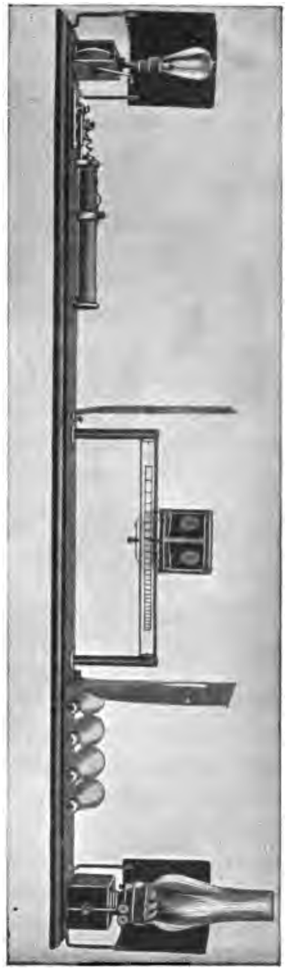


FIG. 75.

Each lamp has in series with it a regulating rheostat for adjusting the voltage. The standard incandescent lamp has many advantages over the oil flame, and its adoption has greatly improved the instrument. Two black cloth screens shield the observer's eye from the rays of the standard and tested lamps. A voltmeter and an ammeter are either placed on the bench or mounted on the back of the instrument in plain view. For rapid work the large illuminated dial type of instrument mounted directly behind the carriage has many advantages, being in plain view and easily read by the observer simply raising his eyes.

Assuming that a commercial photometer, such as one of

those described, has been selected, in which the standard is an incandescent lamp, the arrangement of the circuits for testing may be made in several ways, three of which are given. 1st, A separate circuit for each lamp. 2d, The same circuit for both lamps, with equalizer. 3d, A three-wire circuit fed by a small storage battery. These three methods all assume that the secondary standard is a properly aged and tested incandescent lamp obtained from some reliable laboratory.

The first method, in which a separate circuit is em-

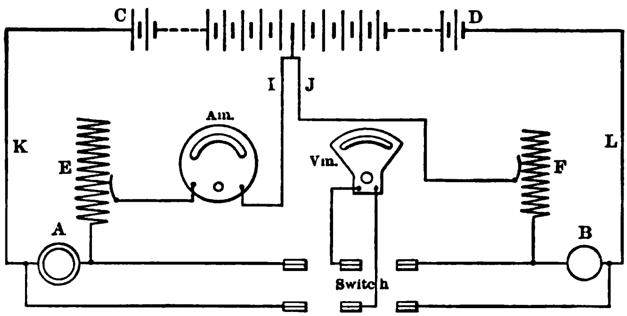


FIG. 76.

ployed for each lamp, is roughly illustrated by Fig. 76, where *A* is the lamp to be tested in the rotating socket, and *B* is the standard lamp. Both lamps are fed from a common two-wire service, *C*, *D*. This is preferable to feeding the lamp from a three-wire service, as the fluctuation in voltage on either side of such a circuit may not be of the same period or amount and thus cause an unevenness in the intensity of either light, which is avoided by using a two-wire service. Variable resistances, *E* and *F*, are connected in series with each lamp respectively, and so

constructed that a small movement of the sliding contact produces only a slight variation in resistance. A common form of such resistance is a cylinder of insulating material wrapped spirally with bare resistance wire over which slides a contact ring.

In series with the lamp, *A*, is placed an ammeter, *Am*, and a voltmeter, *Vm*, is so arranged that by means of a double-throw switch it can be connected to the terminals of either lamp. The voltmeter and ammeter are not essential if a mere comparison of light intensity be made, as any fluctuation in the service e.m.f. affects both lamps alike, but if a wattage test be conducted at the same time, the two instruments are indispensable. The ammeter reading multiplied by the voltmeter reading gives the watt reading, but if the voltage be fairly steady, a close approximation of the wattage may be had by simply observing the ammeter and getting the watt values from a previously prepared table.

If the service be taken from the street mains and the lamps to be tested be for service on these mains, the standard at *B* should be of a lower voltage and the variable resistance should be adjusted to give this lamp the voltage at which it should burn. If a wattage test be made on the lamps, it is extremely annoying to have the voltage remain below the normal for any length of time, and for this reason it is best to have the service come directly from the bur bars in the station, and adjust the voltage at lamps to the proper value by means of the variable resistances. The voltage at the bus bars should be kept very steady, and the resistances in series with the lamps after being once adjusted should need little attention. If a wattage test be made on each lamp, the voltmeter and ammeter are left in circuit with the lamp being tested.

In this connection of lamps a removal of the lamp, *A*, only causes a rise in potential at *B*, equal to the drop on the wires, *C*, *D*, caused by the current consumed by *A*, hence, the voltage of the standard, *B*, is practically unaffected by the removal of *A*. In testing a number of lamps, however, it is found that they will vary considerably in current consumed, and this fact, owing to the variable drop caused thereby in the resistance, *E*, makes the lamp at *A* burn at a different relative voltage to *B*, unless the resistance, *E*, is constantly varied to suit each lamp tested. Therefore, when a comparison is made an error is introduced, unless the resistance, *E*, is changed to give the same relative voltage across *A* that *B* receives. To do this, two

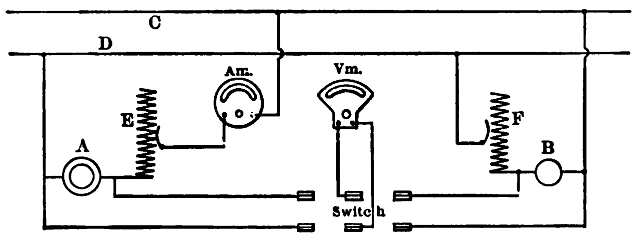


FIG. 77.

voltmeter readings have to be taken, and, in the meantime, the voltage on *C*, *D* may have varied, vitiating the results.

A way of overcoming this trouble is shown in Fig. 77, where the same methods of connection are used, but an equalizing wire connected between *E* and *F* places the resistances in parallel when the two lamps are in circuit. This connection is to be broken when *A* is removed from its socket. For convenience, the breaking of the equalizer connection is so arranged in practice as to be accomplished

by the same operation that removes the lamp, A, from its socket. The voltmeter is connected to the equalizer wire and the wire, C, and indicates the common voltage on both lamps. The wattage of the lamp, A, is the product of the ammeter reading and the voltmeter reading when the equalizer is closed. In both of these first two methods, the candle-power over small ranges of voltage has been assumed to vary on each lamp in the same proportion. But this assumes the same constant for each lamp, which may or may not exist.

The standard lamp and the lamp to be tested may not be possessed of the same physical characteristics or the same

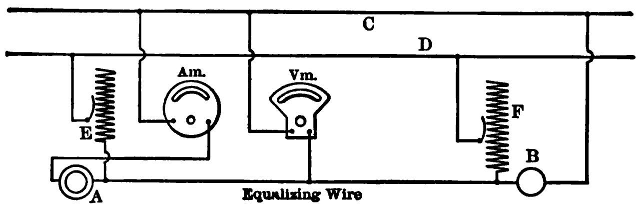


FIG. 78.

ratios of graphitic carbon to base carbon in their filaments, any difference in either of which would have a direct influence on their light-giving qualities at different voltages. To eliminate all errors of this character, the third method wherein a storage battery is employed particularly commends itself to favor.

In Fig. 78, C and D represent two terminals of a storage battery of a sufficient number of cells to give double the potential needed for the lamps, at 1.8 volts per cell. From these cells is led off a three-wire service with two neutral conductors, I and J, connected respectively to one end of

the variable resistances, *E* and *F*, in series with the lamps, *A* and *B*. Leads, *L* and *K*, complete the circuit through the lamps to the positive and negative ends of the battery. This battery may vary in ampere capacity, but for an ordinary central station a capacity of 10 ampere hours at the discharge rate of 1½ amperes per hour is sufficiently large.

The use of the battery provides for each lamp an isolated circuit of its own of absolutely constant potential. The standard lamp at *B* is adjusted to its proper voltage and remains without need of further attention. The object of splitting the neutral is to remove the slight fluctuation caused by the drop in this conductor when the lamp at *A* is removed. One side of the battery alone could be used for both lamps, but the variable demand upon it would cause a slight fluctuation of the voltage at the standard lamp, which should be entirely eliminated for quick work. The voltmeter is connected through a double-pole switch across the terminals of either of the lamps, *A* and *B*, as in first method, and is left in circuit across *A* when a test is being made. Occasionally a reading across *B* is taken, to see if the voltage has varied by the discharging of the battery.

The lamp, *A*, is in a circuit which receives a constant potential, but the potential across the lamp varies with the current taken by the lamp, hence, the variable resistance, *E*, is so placed as to be readily under the control of the operator.

The arrangement of the dark room is a matter which should be carefully planned to enable quick and accurate work to be done. The reading of the instruments should take as little time as possible, and, for this reason, the large illuminated dial type of meter placed directly back of the photometer screen is the best for quick work. These meters

may be mounted in any convenient manner, the controlling switches being within easy reach of the operator.

The scale divisions of the voltmeter should be large, which condition may be secured by using an instrument the range of which extends only about 15 volts above and below the voltage of the lamps to be tested. The ammeter need not read higher than two amperes in 0.01 = ampere divisions. The scales of the instruments should be elevated slightly above the level of the top of the photometer screen; the values can then be read at a glance.

Unless a specific test is being made, an adjustable pointer on the ammeter is of great assistance in rejecting all lamps above a certain wattage, as it can be set at a given value and every lamp which runs the needle over this point rejected at once.

The variable resistance on the lamp to be tested should be within easy reach of the left hand; in fact, the operator's left need never leave it, as his right can be used to shift the screen.

In operating, the lamps to be tested in the rotating socket are removed by a boy who disposes of them according to the reader's call "good" or "bad." Usually the speed of the testing is entirely dependent upon the quickness with which the boy at the sockets can handle the lamps.

The reader's eyes should be shielded from the rays of the standard and tested lamps, and, as it takes several minutes for the eyes to adjust themselves to reading the screen, the reader should not expose his eyes to extraneous light between readings. In testing a large number of lamps where extreme accuracy is not desired, advantage must be taken of every factor which reduces the duration of a test.

THE IMPORTANCE OF PHOTOMETRY TO CENTRAL STATIONS.

The success which the electric light has attained is based primarily on its intrinsic merits, its convenience, cleanliness and adaptability, rendering it superior to any other commercial light, but not necessarily cheaper. Its march forward to the final limit of universal use depends then on two main underlying qualities; first, its superiority over other lights; and second, its ability to compete commercially with other light-giving sources. Almost every day brings forth some new form of light, which the enthusiastic inventor claims will render the electric light obsolete in a very short time. The best answer to such claims is found in the rapid enlargement of the electric central stations in every part of the world.

The price of electricity has shown within the past few years a tendency to become less, as more economical methods of generation are utilized, but it is safe to say that no very radical departure in present prices will come about as long as the efficiency of the incandescent lamp remains at its present low figure. The lamp may be considered the keystone of the entire structure; it is the final link in the series of transformations of energy which take place between the coal-pile and the light, and on its economy (other conditions being favorable) depends the earning power of the central station.

The economy of the incandescent lamp must be viewed from two standpoints, that of the consumer and that of the central station. The light emitted from an incandescent lamp filament increases rapidly as the voltage across the lamp rises, and if the voltage be maintained above normal for any length of time, the life of the lamp is very much shortened. The higher the voltage is raised, the greater

becomes the efficiency of the lamp; that is, the more light per watt of energy it gives.

Viewed from the consumer's standpoint, the lamp should not last more than a few hours for him to get the best returns for his money. This would necessitate such frequent renewals by the central station that the cost of furnishing lamps would be prohibitive. Viewed from the central station's standpoint, the lamp which lasts the greatest number of hours is the best lamp; that is, it needs fewest renewals, and hence is the most economical.

Between the two extremes here presented there must be a mean which should combine the good qualities of both conditions in the greatest possible degree. The perfect lamp would maintain a constant candle-power for an indefinite period with small expenditure of energy; the modern commercial lamp endeavors to give a fairly uniform candle-power for a limited period with an expenditure of energy varying from three to four watts per candle.

It has been found that the long-life lamp is usually of low efficiency to start with, and this efficiency becomes lower as the number of hours the lamp burns increases, until in many instances the efficiency becomes as low as 10 watts per candle. The amount of energy consumed per candle renders the lamp in this condition uncommercial and destroys the quality of its light. In other words, the consumer agrees to pay for light at the rate of three to four watts per candle and will not consent to pay at the rate of 10 watts per candle for an inferior light. The central station, then, in order to fulfil its contract with the consumer, must see to it that the amount of light furnished per watt is maintained at somewhere near the required figure.

Assuming the average total life of the lamp to be 2,000 hours, the power to be 16 candle-power at 3.1 watts per

candle at the start, and 8 candle-power at 6 watts per candle at the end of the 2,000 hours, the mean candle-power and efficiency over the total period may be roughly taken as 12 candle-power at 4.5 watts per candle; in other words, this might be the candle-power and efficiency at the end of 1,000 hours. A new lamp of this quality (12 candle-power at 4.5 watts per candle-power) would be considered uncommercial on a circuit having close voltage regulation. Why, then, should it be tolerated simply because it has had the misfortune to burn 1,000 hours?

The lamp reaches an uncommercial state at some point previous to this time, and the results of a great number of tests have shown that the commercial period of a high-efficiency lamp is reached in about 600 hours burning. The average 3.1 watt-lamp burning at an initial candle-power of 16 has, at the expiration of 600 hours, a candle-power of 13, and an efficiency of 3.7 watts per candle, which may be considered the end of the commercial life of the lamp. The average efficiency of the whole period is 14.5 candles at 3.38 watts per candle.

For a central station to compete successfully with Welsbach and other lights, the candle-power of the lamps of the entire service must be maintained at a high standard. To do this successfully a system of periodic renewals must be instituted, the frequency of which can be roughly estimated from the consumer's bills. If a consumer having 10 lamps develop a gross bill of $10 a month at one cent per lamp hour, the average service per lamp is 100 hours, and the renewals of lamps need only be made twice a year.

The maintenance of a clean lighting service, without any waste in the lamps displaced by renewals, necessitates the photometering of all the lamps returned. The lamps in the consumer's premises frequently become fly-specked

and covered with dust so that it is impossible to judge of the true candle-power of a lamp until it is cleaned. As the lamps must be changed by cheap labor, it is best not to invest this labor with powers of discrimination, but to have all the lamps in a given installation changed regardless of their appearance.

Some idea of the total cost of renewals in lamps may be gained for any station by proceeding as follows: In a typical plant, assume 1000 16 c.-p. lamps connected, and a gross income of $3,650 per annum at ¾ cent per lamp hour. Then the average income per day will be $10, corresponding to 1333 lamp hours a day, or 1.3 hours per lamp per day. Allowing 600 hours per lamp as the commercial life, each lamp would last 461 days, requiring the renewal of about 800 lamps per year. This figure is somewhat higher than would be met in practice, but it amounts to less than five per cent. of the gross income. The increased income from good service would more than counterbalance the cost. This policy on the part of a central station would be very popular and could be used effectively in soliciting new business and settling disputed bills, not to mention the inducement it gives the consumer to burn more light.

To return to the photometric features of the work, the renewal of lamps should be carried out daily, and the returned lamps cleaned preparatory to testing. The tested lamps are divided into two classes, those testing between 13 and 16 candle-power are retained as a sort of second-class stock, and those testing up to 16 candle-power and over are treated specially, and considered as first-class stock.

If the first-class stock be in the majority, the lamps are tested for this class first; if the second-class stock be the